IRRIGATION PUMPING PLANT PERFORMANCE AND PUMP EFFICIENCY DECREASE WITH AGE

By

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INTRODUCTION

Irrigation is one of the largest consumers of on-farm energy in the U.S.. According to Gilley (1983), much of the water used for irrigation is supplied with pumped water (about 72% of the total irrigated land in the U.S. in 1979). About 3% of the total national energy usage is used to satisfy agricultural demands, and from that about 23% is devoted for pumping water for irrigation. These statistics, however, are global and include many regions in the U.S. in which irrigation is only a complementary agricultural practice as well as others where pumping water is essential for crop production. For example, Gilley (1983) reported that in Texas, 65% of the total energy used to produce irrigated grain sorghum is utilized to pump water. In Nebraska, 40% of the on-farm energy usage is designated to pump water. In Arizona, the energy required for pumping water is between 73% and 96% of the total on-farm energy usage.

In Kansas, three factors are motivating irrigators to look for better energy-usage management: 1) The decrease of the water level of the aquifers, particularly the Ogallala which is the main supplier of irrigation water for Western Kansas. 2) The escalating prices of oil, and 3) The tendency of irrigators to shift from gravity to sprinkler systems, most likely to center pivots.

In the first case, from 3,488,141 acres of irrigation land in Kansas, 3,083,000 acres are suffering an average decline of at least half a foot per year in the aquifer level (Slogget, 1981). This means that as the years pass more energy will be required since the total dynamic head will increase because of a drop in the water level in the aquifers. The second factor is of an economical nature and is closely related to the profitability of irrigated crops. Finally, the shift from gravity to sprinkler irrigation implies the addition of extra pressure to the system which also increases drastically the total dynamic head and by the way, the energy usage.

As these factors become greater with time, the need for reducing the energy usage in pumping water is imperative. Such energy may or may not be efficiently spent. Generally, a large amount of extra energy is wasted as the pumping plant works inefficiently. Either the problem is because of poor performance of the power unit or the pump. The repercussion of inefficient performance of pumping plants may be translated into spending more energy than is necessary for pumping the same amount of water required for crop production. As a consequence, more money has to be devoted to satisfy the same needs of crops for water.

A pumping plant test is made in order to determine how a pumping plant is performing in comparison with the Nebraska

Pumping Plant Performance Criteria (NPPPC) (Schroeder, 1982). Consequently, the test will indicate whether the pump or the power unit, or both, are working efficiently, or on the other hand, inefficiently. With the diagnosis of the pumping plant performance the irrigator may consider several alternatives including adjusting, repairing, replacing the pump and/or the power unit. Other decisions that might be considered include shifting to another energy source, choosing the convenience of applying water at different flow rates, shifting to another irrigation system, etc. Generally, the decision the irrigator takes will be based on economic factors.

Since this subject is of relevant interest for improving the Kansas agricultural energy-usage, this research has been conceived to comply with two main objectives:

1.- To evaluate the performance of pumping plants in Kansas during the period from 1981 to 1988.

2.- To establish the relation between the age of the pump and the decrease in efficiency of the same.

The first part of this research presents a global scope of the performance of pumping plants and the efficiencies of power units and pumps in Kansas.

It is intended that the results of the second objective of this investigation will be incorporated in the model and computer program ICEASE (Irrigation Cost Estimator and System Evaluator) developed by Williams et al. (1986). This program

currently lacks a parameter that considers the efficiency decline of pumps with age.

Although the latter part of the research did not achieve consistent conclusions, it will provide an important reference for future research since this is possibly the first attempt made to derive a relation between pump decrease in efficiency and pump age. The philosophy of this part of the investigation is that it would be better to achieve more exact conclusions in terms of accuracy for predicting pump decrease in efficiency with age. The approximation achieved has been developed from about 45 pumping plant tests. It is safer to use the approximation for design, planning and economical considerations than to assume it without any criteria until better prediction models can be developed.

REVIEW OF LITERATURE

Previous Studies

Extensive work has been done in the field of pumping plant performance evaluations during the last four decades, mainly in the states of Nebraska, Texas, New Mexico and Kansas.

The first experience of this kind was reported by the University of Nebraska in 1962 in which 7 pumping plants were tested during the period from 1956 and 1962 (Schroeder et al., 1984).

In 1968, the Texas Technologic College made an extensive research directed to find out the behavior of the efficiencies of pumping plants in the High Plains of Texas, including relatively small regions of the states of New Mexico, and Oklahoma (Agricultural Engineering Department, Texas Tech, 1968). This study reported that the amount of water applied varied considerably throughout the area covered by the project because of the lowering of the water table, badly worn pumping equipment, inefficient design of both pump and well, improper installation of equipment, different types of power units, and lack of maintenance of the power units. They also made an economical analysis of pumping plants to determine what type of power units were operating more economically under the different conditions of pumping lift, amount of water used and

size of the power unit. They found that, for the range of pumping plants tested in the project, the average total cost of pumping irrigation water in $/acre-ft/foot of TDH (total dynamic head) is greater per unit as the WHP (work output) of the pump decreases, regardless of the type of power unit used. When the source of energy is considered, the research points out that pumping plants with propane engines have the highest unit cost in $/acre-ft/foot of TDH of water pumped, principally because of the inherent relatively low efficiency and of the high fuel costs for these types of power units. Pumping plants with electric motors with less than 30 HP were found economically more advantageous in terms of cost of pumping water than the other power units. If the BHP is between 30 and 60 HP the difference between the average total cost of pumping water with electric motors or natural gas engines is small and any factor could provide advantage for one type or another. However, for power units with BHP greater than 60 HP the natural gas engines were proven to be the most economical fuel source for pumping water.

In 1978, New Mexico State University and the New Mexico Energy Institute conducted a pumping plant efficiency study of pumping units powered principally by natural gas engines (Abernathy et al., 1978). They found that the average power unit efficiency of the 285 natural gas engines tested was 21.4% and the corresponding value for 9 diesel engines was 28.9%.

A similar study conducted in 1980 in the Texas High Plains, was reported by The Cross Section (1980), in which the efficiencies of 91 natural gas engines were tested. The average efficiency found for those engines was 20.6%.

During the period 1980 to 1982 the University of Nebraska directed the "Irrigation Pumping Plant Performance Demonstration" (PUMP program). They made about 189 pumping plant tests with the aim to demonstrate and convince the farmers about the importance that a test of this kind would have on improving the performance of their pumping plants and, thus, saving money and energy for the state (Schroeder et al., 1984). In general, they found that the average pumping plant performance rating was 77% of the Nebraska Criteria and that typical pumping plants were using about 30% more energy than necessary. In the report, they estimated that because of the poor performance of the pumping plants powered by diesel engines, Nebraska was wasting about 60 million gallons of diesel in a typical year.

In 1982, The Northwest Kansas Groundwater Management District (1982), reported a pumping plant performance project. Twenty four pumping plant tests were made during the project in the northwest region of Kansas for the purpose of making a general evaluation of the performance of pumping plants. All the retests were excluded from the analysis. They found that the average pumping plant performance rating was about 69.9%. If the fuel source is considered, the average performance

rating for pumping units powered by natural gas engines was 65.6%, and for electric pumping units, 78.7%. For the two diesel pumping plants tested, the average rating was 63.75%. Finally, only one propane pumping plant was tested and no average was reported for this case.

The last research that is known to have been made in this field was reported by Schneider (1986). He analyzed the power unit efficiencies of pumping plants powered by natural gas and diesel engines in the region of the High Plains of Texas. Regardless whether or not the engines were of industrial or automotive type, he concluded that from 240 natural gas engines tested, only 16% of them met or exceeded the Nebraska recommendation, and only 23% of the 26 diesel engines tested were at or above the recommended point of efficiency. The average, low, and high values of efficiency determined were 20.5%, 7.8%, and 28.9% for natural gas engines, and 31.2%, 26%, and 34% for diesel engines.

Pumping Plant Performance Theory

Irrigation Pumping Plants

An irrigation pumping plant is composed of two elements: the pump, and the power unit. There are three types of pumps used for irrigation: vertical turbine, centrifugal, and submersible. From these types, the vertical turbine type is the most common in Kansas because almost all the water used for crops in irrigation comes from deep wells. Submersible pumps are also suitable for deep wells, but traditional practices make them very difficult to find in Kansas. Power units refer to the electric motors or the engines powering the pump plus the gear head and the line shaft. Generally, electric motors are of the vertical, hollow shaft type and their shafts are directly connected to the shafts of the pumps so that they do not require gear heads or belts to drive the pumps. There are four different types of engines according to the fuel they consume: diesel, propane, natural gas, and gasoline. Natural gas engines are the most common followed by the diesel engines, and then by the propane engines. Gasoline engines are so scarce in Kansas that they will not be considered in this research.

Pumping Plant Tests

A pumping plant test consists of a series of measurements that are made on both pump and power unit and which will be

used later to diagnose their performance in comparison with a universally accepted standard called Nebraska Pumping Plant Performance Criteria (NPPPC). Generally, the measurements are aimed to determine the overall performance of the pumping plant, and to obtain the individual performances of the pump and the power unit. However, regardless of the purpose of the test, the following measurements must be made (for further information see Schroeder, 1985):

a) Pump Flow Rate: This is the discharge of the pump measured in gallons per minute (GPM). Generally, this measurement is made using either the Collins Flow Gauge or the Propeller Flow Meter.

b) Pumping Water Level: It is also called dynamic water level or "lift" and it refers to the vertical distance between the centerline of the pump and the water level once the aquifer has stabilized. It is measured in feet (in the U.S.) and will be symbolized by PWL. For deep well turbine pumps this measure is made using the electronic water level indicator or the air-line method. For centrifugal pumps the measure may be made using a vacuum gauge.

c) Operating Pressure: This measurement is made using a pressure gauge at the discharge end of the pump. It is measured in pounds per square inch which will be represented by the letters PSI.

d) Fuel or Energy Consumption Rate: For electric motors it

is measured in KW-h/h, for diesel and propane engines in gal/h, and for natural gas engines in mcf/h (thousands of cubic feet per hour). It will be symbolized by ECR.

The following measurements are not essential for evaluating the performance rating of a pumping plant; however, without them it is not possible to determine the pump and power unit efficiencies if the pumping plant is not powered by an electric motor:

a) Torque: This measurement is almost made exclusively on pumping plants powered by engines. In electric motor units the task is quite difficult and not necessary because it is possible to determine pump and power unit efficiencies without this measurement. The units used for the torque are ft-lbs and is symbolized by the letters TORQUE.

b) Pump Rotation Speed: It is measured in revolutions per minute (RPM).

c) Drive Rotation Speed: Together with the torque the drive rotation speed is used to determine the output power (BHP) of the power unit. Its units are given in RPM.

Other information that is not essential for pumping plant performance evaluations but could be used for analysis and recommendations are the following which have been adapted from the field sheet forms of the Soil Conservation Service of Kansas, KSU Agricultural Engineering Department, Northwest Kansas Groundwater Management District, Servi-Tech and from

Schroeder, (1982):

a) Pump Information:

- Brand
- Serial Number
- Bowl and Impeller Model
- Number of Stages
- Pump Setting
- Static Water Level
- Column Size (diameter)
- Line Shaft Size (diameter)
- Head Shaft Threads
- Impeller Trim Size
- Year of Installation
- Hours of Operation a Year

b) Power Unit:

- Brand
- Serial Number
- Model
- Displacement
- Fuel Type
- Normal Operating Speed
- Continuous HP
- Installation Year

c) Gear Head:

- Brand
- Serial Number

- Gear Ratio
- Gear head HP
- Installation Year

d) Well:

- Well Driller
- Location of Well
- Diameter of Well and Casing
- Depth
- Cascading Water
- Installation Year

e) Farm Information:

- Owner
- Address
- County
- Area Irrigated
- Cost of Fuel
- Fuel BTU rating (in case of natural gas)
- Water Depth of Application
- Type of Irrigation System

For purposes of illustration, in the appendix (Tables 13, 14, 15, and 16) are presented the field sheet forms currently being used by the Soil Conservation Service, KSU Agricultural Engineering Department, Servi-Tech, and the Northwest Kansas Groundwater Management District.

Pumping Plant Performance

Once the pumping plant test is finished it is necessary to follow the next steps to calculate the performance of a pumping plant:

a) Total Dynamic Head: This is the head that the pump is operating against. It is calculated by the equation:

$$TDH = PWL + PSI * (2.31) + H_f \qquad [1]$$

Where PWL = Pumping Water Level in Ft.

PSI = Operating Pressure in psi.

H_f = Pump Column Friction Loss.

b) Water Horsepower: Work output of the pump stated in terms of horsepower.

$$WHP = \frac{(GPM) * (TDH)}{3960} \qquad [2]$$

Where GPM = Pump flow rate.

c) Pumping Plant Performance: It is the pumping plant work output per unit of energy consumption rate. It is given in units of WHP-h/KW for electric-powered pumping plants, WHP-h/gal for diesel and propane, and WHP-h/mcf for natural gas pumping units. It is calculated by the formula:

$$PPP = \frac{WHP}{ECR} \quad [3]$$

Where ECR = Energy or fuel consumption rate.

Nebraska Pumping Plant Performance Criteria

In the Irrigation Pumping Plant Performance Handbook, Schroeder (1982) defines this parameter as follows: "The NPPPC represents the performance level which can be expected from a well designed and maintained pumping plant. It is a compromise between the most efficient pumping plant possible and the average pumping plant." The NPPPC is intended to serve as a guide which will indicate whether a pumping plant is performing satisfactorily or not. Although experience tells that more than half of the pumping plants in a large random sample perform below this standard, it is also possible to find a small number of pumping plants that exceed this criteria. The NPPPC is generally given in english units, consistent with those assigned to the pumping plant performance (PPP) discussed in the last section. Finally, in Table 1 the performance values recommended by Nebraska are shown.

Table 1. Nebraska Pumping Plant Performance Criteria.

ENERGY SOURCE	NPPPC[a]
Electric	0.885 WHP-h/KW[b]
Diesel	12.5 WHP-h/gal
Propane	6.89 WHP-h/gal
Natural Gas	66.7 WHP-h/mcf[c]

[a]WHP-h/unit of energy. Standard performance of the pumping plant -both power unit and pump. Values are based on 75% pump efficiency.

[b]Assumes 88% electric motor efficiency.

[c]Assumes natural gas energy content of 1,000 BTU/ft^3.

Table adapted from Dorn et al. (1982).

The NPPPC has based its values of optimum performance assuming 75% pump efficiency, 88% electric motor efficiency and an energy content of 1,000 BTU/ft^3 for natural gas fuels. However, pump efficiencies are slightly better as the size of bowls increase and the number of stages increase (Northwest Kansas Groundwater Management District, 1982). The figure of 88% given by the NPPPC for electric motors is based on motors rated from 10 to 40 HP, and in practice many motors are rated larger than that. Finally, the BTU rating of natural gas fuels is not always 1,000 BTU/ft^3 as assumed by the NPPPC. Consequently, some corrections must be made to the pump, to the electric motor (if applicable), and to the energy content

of natural gas fuels, in order to approach reality a little more. These corrections are presented in Tables 2 and 3, and in formula [4].

Table 2. Pump Correction Factors.

Number of Bowls	Correction Factor for 6" and 8" bowls	Correction Factor for 10" and larger Bowls
3 or more	1.020	1.07
2	0.988	1.06
1	0.948	1.02

Table reproduced from Northwest Kansas Groundwater Management District (1982).

Table 3. Electric Motor Correction Factors.

Motor Size HP	Correction Factor
2 - 7.5	0.932
10 - 40	1.000
50 - 75	1.040
100 - 400	1.050

Table reproduced from Northwest Kansas Groundwater Management District (1982).

NATURAL GAS CORRECTION = 0.0667*(BTU RATING) [4]

Where BTU rating = Energy content of natural gas fuels.

Adjusted NPPPC

This is the original NPPPC multiplied by the pump and/or motor correction if applicable. It is given by the equation:

$$(NPPPC)_a = (NPPPC)*(PUMP\ CORRECTION)*(MOTOR\ CORRECTION) \quad [5]$$

Where NPPPC is taken from Table 1, and the pump and the motor correction from Tables 2 and 3, respectively.

Pumping Plant Performance Rating

It is the ratio of the pumping plant performance to the adjusted NPPPC, expressed as percent.

$$PPPR = \frac{PPP}{(NPPPC)_a} * (100) \quad [6]$$

Where PPPR is the Pumping Plant Performance Rating.

From now on, the term NPPPC will be used in this thesis when referring to $(NPPPC)_a$, the adjusted NPPPC.

Pumping Plant Efficiency Calculations

Overall Efficiency

The overall efficiency (EFF_{all}) refers to the pumping plant efficiency as a whole, without considering the individual efficiencies of the pump and the power unit. It can be calculated in two ways: first, multiplying the PPPR by the Nebraska Standard for overall efficiency, and second multiplying the pump efficiency by the power unit efficiency. The two procedures are mathematically described next:

$$EFF_{all} = PPPR * (\text{NEBRASKA STANDARD FOR } EFF_{all}) \quad [7]$$

Where the Nebraska Standard for Overall Efficiencies is given in Table 4.

Table 4. Overall Efficiency of Pumping Plants at 100% NPPPC.

Energy Source	PPPR	Nebraska Overall Efficiency
Electric	100 %	66 %
Diesel	100 %	23 %
Propane	100 %	18 %
Natural Gas	100 %	17 %

Reproduced from Schroeder (1982).

In case both the power unit and the pump efficiencies are known, the calculation is made as follows (Longenbauch,

1983):

$$EFF_{all} = (EFF_{pu}) * (EFF_{pump}) \qquad [8]$$

Where EFF_{pu} = Power unit efficiency, and

EFF_{pump} = Pump efficiency.

Power Unit Efficiency

This is the ratio of the work output (BHP) to the input horsepower (IHP) of the power unit. It can be calculated by the equation:

$$EFF_{pu} = \frac{BHP}{IHP} *(100) \qquad [9]$$

Where the BHP is the value of the horsepower delivered to the power unit drive shaft. For engines, the BHP is calculated as follows:

$$BHP = \frac{(TORQUE) * (DRIVE\ RPM)}{5252} \qquad [10]$$

Where the torque and the drive RPM have been measured previously in a pumping plant test.

For electric motors it is assumed that their efficiency does not decrease with time, and that if a motor is running,

its efficiency will be at or very close to peak efficiency provided the motor is loaded between 75% and 125% of rated load (Longenbauch, 1983). Thus, the BHP is given by:

$$BHP = (IHP)*(EFF_{electric\ motor}) \qquad [11]$$

and,

$$EFF_{electric\ motor} = (88\%) * (MOTOR\ CORRECTION) \qquad [12]$$

The Motor correction factor is taken from Table 3, in case that the motor size is not between 10 and 40 HP.

The input horsepower is the energy in form of fuel that the power unit consumes in order to operate the pumping plant. For convenience, energy in the form of gal/h of diesel or propane, or mcf/h of natural gas is translated to units of horsepower using the formula:

$$IHP = \frac{(ECR) * (BTU\ rating)}{2545.1} \qquad [13]$$

Where ECR = Energy or fuel consumption rate, and the BTU rating of various energy sources are given in Table 5.

Table 5. BTU Rating of Different Fuels.

Energy Source	BTU rating
Diesel	140,000 BTU/gal
Propane	92,000 BTU/gal
Natural Gas	925,000 BTU/mcf

Note: 925,000 BTU/mcf is the most common BTU rating for natural gas fuels. However, it can vary from 925,000 BTU/mcf to 1,000,000 BTU/mcf.

Adapted from Northwest Kansas Groundwater Management District (1982).

Pump Efficiency

The pump efficiency is the ratio of the WHP to the BHP of the pump.

$$EFF_{pump} = \frac{WHP}{BHP} * (100) \qquad [14]$$

Where EFF_{pump} = Pump efficiency.

PUMPING PLANT PERFORMANCE EVALUATIONS

Data Collection

Four hundred eighty six pumping plant tests results were collected from four sources: a) Agricultural Engineering Department of Kansas State University which provided 67 tests, b) Northwest Kansas Groundwater Management District that gave 22 tests, c) Soil Conservation Service contributed with 142 tests, and d) Servi-Tech, a consultant company that provided 255 tests. The data given by the KSU Agricultural Engineering Department and the Soil Conservation Service covered the period from 1984 to 1988, while the data corresponding to the Northwest Kansas Groundwater Management District and Servi-Tech were within the period from 1981 to 1984.

On the one hand, according to a survey made in Kansas in 1982, about 25,500 pumping plants were irrigating about 3,488,141 acres of land in Kansas (Thomas, 1982). The number of deep well turbine-type pumping plants operating were about 24,212 and about 1,288 were of centrifugal type. In this study the centrifugal-type pumping plants are not considered for further analysis of performance evaluations. For effects of estimation of energy expenditures and excess fuel usage in this state, however, they are taken into account. The main reason for this is because only the total number of units falling in each pump-type group (deep-well or centrifugal pumps) are known; however, no differentiation has been made

in the number of pumping units in each pump-type group, according to their fuel source which is one of the most decisive variables. Since the deep well pumping plants account for 95% of the total units that were irrigating in 1982, the centrifugal-type units were added in order to have a grand total of 25,500. It is assumed that the error due to the addition will not distort the results. With this assumption, pumping plants powered by electric motors account for 19% of the total, those powered by diesel engines 15%, those with propane engines 7%, and the units powered by natural gas engines 59% of the total (Figure 1).

On the other hand, the distribution of pumping plant tests by fuel source collected has some differences with respect to the actual distribution of pumping plants powered by different fuel sources. As shown in Figure 2, the electric pumping plant tests collected represent 33.7% of the total, compared with 19% obtained from the survey. Pumping units collected powered by diesel and propane engines are 9.2% and 3.5%, respectively, compared with 15% and 7% of the survey. The sample collected that included the natural gas engines has more affinity to the 1982 survey. In the first case, the sample represents 53.6% of the total. In the second case, 59%. The above discussion indicates that the data collected represents a sample with a relatively higher percentage of electric-type units in comparison with the total population of electric pumping plants, a lower percentage of units

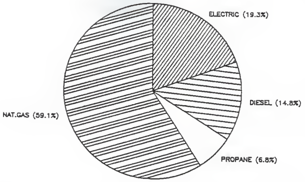

Figure 1. 1982 Pumping Plant Survey in Kansas. Distribution by Fuel Source. (Source: Thomas, 1982).

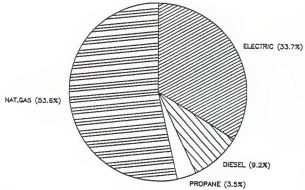

Figure 2. Pumping Plants Tests Evaluated. Distribution by Fuel Source.

powered by diesel and propane engines, and about the same with regard to the percentage of the sample and the total population of pumping plants powered by natural gas engines.

Pumping Plant Performance Rating

The pumping plant performance for each individual test was made and compared with the Nebraska Pumping Plant performance Criteria (NPPPC) in order to obtain their performance rating. The methodology used for these evaluations is described fully in the review of literature of this thesis. All the performance rating calculations were distributed in frequency intervals taking into consideration the energy source and the total overall distribution as shown in Figure 3. According to this figure, 14.2% of the pumping plants tested met or exceeded 100% NPPPC, 11.5% were working satisfactorily in the range of 90% to 99%, 50.1% were performing moderately between 60% and 89%, and 24.2% were performing below 59% of NPPPC. Thus, the majority of the pumping plants (85.8% of the total tested) were working below the NPPPC. Considering that this sample represents the behavior of the total population of pumping plants in Kansas, it is easy to observe that it is unlikely that a typical pumping plant is attaining the NPPPC.

The average performance rating of the total sample was 74.3% with low and high of 12.7% and 127.9% of NPPPC,

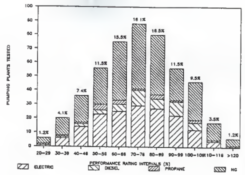

Figure 3. Pumping Plant Performance Rating.
Total Distribution and by Fuel Source.

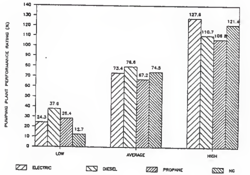

Figure 4. Pumping Plant Performance Rating.
Extreme and average values.

respectively. Notice that the average performance rating reported by Nebraska in 1982 was 77% of NPPPC, which is about 2.7% higher than that determined for Kansas. The averages, lows, and highs graphed against performance rating and taking into consideration the fuel source are shown in Figure 4. The averages shown in this figure are not statistically different from each other ($\alpha = 0.05$) even though the samples of pumping plants powered by diesel and propane engines are considerably smaller than the samples powered by electric motors and natural gas engines.

The average performance rating made for each year of the period ranges from a high of 82.2% in 1982 to a low of 60.5% in 1985 as is shown in Table 6. From 1981 to 1983 the performance rating average values are higher than the whole period mean; however, from 1984 to 1988 the averages are lower than for the period mean. In Table 6 the number of pumping plants tested is presented along with the average and standard deviation of their performance rating. These values are computed in each of the years of the period. Also the differences of the average performance ratings of each of the individual years with the average computed during the whole period are calculated. As it is shown in Table 6, the average PPPR for the years 1987 and 1988 were determined using only 6 and 21 data points, respectively.

Table 6. Average PPPR distribution by year.

YEAR	PUMPING PLANTS TESTED	AVERAGE PPPR (%)	PPPR ST DEV (%)	DIFFERENCE ABOUT THE PERIOD MEAN
1981	103	81.8	20.0	7.5
1982	72	82.2	20.0	7.9
1983	93	77.0	22.0	2.7
1984	65	70.7	20.8	-3.6
1985	53	60.5	20.7	-13.8
1986	73	67.4	16.7	-6.9
1987	6	73.0	14.4	-1.3
1988	21	69.2	17.3	-5.1
81-88	486	74.5	21.3	

Excess Energy Usage

The consequences of poor performance of pumping plants are reflected in the way they use more energy than necessary. In other words, as the performance rating gets lower, the excess energy usage increases without making any extra useful work for pumping water. The excess energy usage is the complement, in percent, for a pumping plant to meet 100% of the NPPPC. This concept is applicable only to pumping plants performing below 100% NPPPC. It can be calculated by the formula:

EXCESS ENERGY USAGE(%) = 100% - PPPR(%) [15]

During the period studied, the average excess energy usage was about 30.5% with a low of 0.4% and a high of 87.3%. Strictly, speaking the real lowest value of excess energy usage would be 0%. Nevertheless, this analysis only considers

pumping plants working below the NPPPC. For the different energy sources the lows, averages, and highs are shown in Figure 5. Notice that the averages of excess fuel usage for pumping plants powered by electric motors and natural gas engines are close to the overall average, and those corresponding to diesel and propane engines differ by -6% and 7.5%, respectively, from the overall average. This is due presumably to the scarcity of data points of the samples corresponding to diesel and propane pumping plants.

Approximately 14% of the pumping plants evaluated were using 51% to 70% more energy than required, 46% were wasting 31% to 70% extra energy and about 52% were spending between 1% and 30% more fuel than necessary (Figure 6).

The average distribution of excess fuel usage computed during the total period is statistically different from the averages computed on each of the years comprising the period of study. The higher difference takes place in 1985 with an average excess energy usage of 39.5% compared with the period average of 30.5% (see Table 7).

A rough estimate of the amount of KW-h, gallons of diesel and propane fuels, and mcf (thousands of cubic feet) of natural gas wasted unnecessarily in a typical year during the 1981-1988 period was computed assuming that the total number of pumping plants reported in the survey of 1982 has been maintained steady over the years during the period of study, and that the average pumping hours per year is 2,000. One

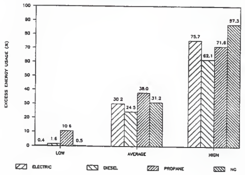

Figure 5. Excess Energy Usage.
Extremes and Average Values.

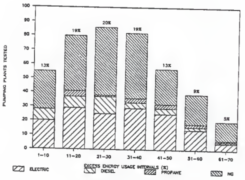

Figure 6. Excess Energy Usage.
Total and by Fuel Source Distribution.

further assumption necessary for this estimate is to consider the 1,288 surface-water pumping units as deep-well pumping plants.

Table 7. Average Excess Fuel Usage by Year

YEAR	PUMPING PLANTS TESTED	AVERAGE EXCESS ENERGY (%)	EEU STD DEV (%)	DIFFERENCE ABOUT THE PERIOD MEAN (%)
1981	80	26.3	14.9	-4.2
1982	55	26.7	13.1	-3.8
1983	77	29.3	18.7	-1.2
1984	64	29.9	20.5	-0.6
1985	53	39.5	20.7	9.0
1986	71	33.5	15.9	3.0
1987	6	27.0	14.4	-3.5
1988	21	30.8	17.3	0.3
81-88	427	30.5	17.9	

The excess fuel usage in terms of KW-h/h, gallons of diesel or propane per hour (gal/h) and mcf/h can be calculated by the following equation:

$$\text{EXCESS FUEL USAGE} = (1 - \text{PPPR})*(\text{FUEL USE}) \qquad [16]$$

Where PPPR must be input in decimals and the fuel use in units of KW-h/h, gal/h or mcf/h.

In this sense, the excess fuel usage is calculated for all the pumping plants evaluated and the averages are determined according to the different fuel sources (electric, diesel, propane and natural gas). Then the averages by fuel source are multiplied by the number of pumping plants reported

in the 1982 survey (Table 8).

Table 8. Average Excess Energy Usage and Average Costs of Extra Energy.

TYPE OF PU OR ENERGY SOURCE	TOTAL No OF PUMPING PLANTS IN KANSAS Survey: 1982	EXCESS FUEL USAGE BY A TYPICAL PUMPING PLANT (1981-1988)	ESTIMATE OF TOTAL EXCESS ENERGY USAGE IN A TYPICAL YEAR (1981-1988)	AVERAGE PUMPING HOURS PER YEAR (assumed)
ELECTRIC	4930	7.008 KWh/h	34551.6 KWh/h	2000
DIESEL	3779	0.988 gal/h	3651.1 gal/h	2000
PROPANE	1729	1.841 gal/h	3182.6 gal/h	2000
NAT.GAS	15062	0.255 mcf/h	3846.6 mcf/h	2000
TOTAL	25500			

TYPE OF PU OR ENERGY SOURCE	TOTAL ENERGY WASTED UN-NECESSARILY IN A TYPICAL YEAR (1981-1988)	COST OF ENERGY (1989) ($)	MONEY WASTED UNNECESSARILY DUE TO POOR PERFORMANCE OF PUMPING PLANTS ($)	AVERAGE MONEY WASTED BY A TYPICAL PUMPING PLANT ($)
ELECTRIC	8.910E+07 KWH	0.07	4,837,228	981
DIESEL	7.302E+06 gal	0.70	5,111,495	1,352
PROPANE	6.365E+06 gal	0.40	2,548,092	1,473
NAT.GAS	7.694E+06 mcf	3.50	26,927,779	1,788
TOTAL			39,422,592	

NOTE: The fuel costs vary from place to place all Kansas wide. The costs given in this table are estimates obtained from gas companies.

The results indicate that in a typical year over the period of study the expected rates of energy wasted are 34,551.6 KW-h/h, 3,651.1 gal/h, 3,182.6 gal/h and 3,846.6 mcf/h for pumping plants powered by electric motors, diesel, propane and natural gas engines, respectively. Furthermore, if it is assumed that pumping plants work an average of 2,000 hours a year, the total energy wasted in a typical year over the period considered resulted to be about 69.1 million of KW-h, 7.3 million of gallons of diesel, 6.37 million of gallons of propane, and 7.69 million of mcf. Consequently, an average

of about $39.4 million is wasted in a typical year of the period 1981-1988 due to poor performance of pumping plants. As shown in Table 8, the average costs of excess fuel not utilized to pump water in a typical year of the period under consideration is about $4.8 million for pumping plants powered by electric motors, $5.1 million for units with diesel engines, $2.5 million for units with propane engines, and $26.9 million for pumping plants with natural gas engines. Thus, the average cost unnecessarily paid by a typical pumping plant powered by electric motors, diesel, propane, and natural gas engines is, respectively, $981.00, $1,352.00, $1,473.00, and $1,788.00. The electric-motor pumping plants have the lowest cost of money wasted per unit mainly because of the high or near peak efficiencies of their power units. Their only means of inefficiencies are because of the pump. In the case of engine-powered pumping plants, both the engine and the pump contribute to extra expenditure of energy and money. Diesel engines are inherently more efficient than propane and natural gas engines. This seems the reason for the average extra cost per unit of diesel-powered pumping plants being cheaper than for propane or natural gas pumping units. Similarly, propane engines are slightly more efficient than natural gas engines. Thus, the average extra cost per unit of propane pumping units is lower than for natural gas pumping plats. In conclusion, the average extra cost per unit for natural gas pumping plants is the largest of all.

Energy Expenditure

The energy expenditure spent in a typical year during the period under consideration was roughly estimated in units of Mega Joules per Hour (MJ/h) and by fuel source. The energy expenditure takes into account both the energy used efficiently by those units working at or above 100% NPPPC, and the energy wasted by units working below 100% NPPPC. In order to compare the energy consumed by irrigation pumping plants with different fuel sources, the fuel rate consumed by individual units was converted to units of HP (IHP) and then to units of MJ/h (1HP = 2.685 MJ/h).

Without considering the fuel sources, the average energy expenditure in a typical year during the period 1981-1988 was about 634 MJ/h with a low of 17 MJ/h and a high of 3,052 MJ/h.

The individual estimations of average yearly energy expenditure were computed in order to determine how far they departed from the period mean. In Table 9, it can be noticed that the yearly averages for the years 1981, 1982, 1983, 1984, and 1986, depart from the period average with a maximum difference of about 91 MJ/h. In years 1985 and 1988, however, the differences are in the order of 274 MJ/h and 185 MJ/h below the period mean. In 1987 the average is higher than the period's average by about 182 MJ/h. It is possible that the high differences encountered in the years 1987 and 1988 are induced by the low number of data points included in the

analysis.

Table 9. Average yearly energy Expenditure.

YEAR	AVERAGE ENERGY EXPENDITURE (MJ/h)
1981	672.3
1982	725.1
1983	701.6
1984	631.6
1985	449.4
1986	602.3
1987	816.6
1988	357.8
81-88	633.7

The averages, lows, and highs of energy expenditure for the four fuel sources considered are presented in Figure 7. It is noticed clearly that electric-motor pumping plants have the lower lows, averages, and highs (in MJ/h) compared to the other fuel sources. On the other hand, pumping units powered by natural gas engines are the largest consumers of energy in comparison with the other energy sources.

Although the pumping plants powered by electric motors represent about 19% of the total units operating in Kansas (Figure 1), the average energy consumption in a typical year of the period 1981-1988 is about 3.1% of the total (Figure 8). Natural gas units, however, consume 77.9% of the total energy expenditure even though they represent only about 59%

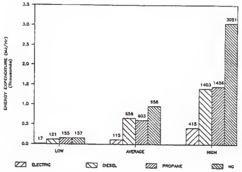

Figure 7. Energy Expenditure.
Extremes and Average Parameters.

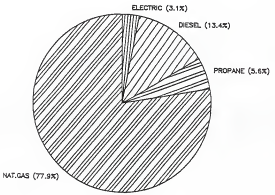

Figure 8. Pumping Energy Expenditure in Kansas.
Distribution by Energy Source.

of the total. For diesel and propane engines the latter comparison is not so dramatic as can be seen in Figures 1 and 8. This situation is shared by the distribution of pumping plants by fuel source and the distribution of energy expenditure by fuel source, encountered in the continental U.S.(Figure 9). Electric pumping units consume only 25.2% of the total energy spent in irrigation; however, they still represent 46.4% of the total number of pumping plants. On the other hand, although the percentage of natural gas pumping units is only 25.1%, they consume about 40.6% of the total energy used for irrigation pumping in the U.S.. In both the U.S. and in Kansas, the relatively high consumption of energy that natural gas engines has is due principally to the greater water depths that pumps have to work against in the regions where natural gas is a popular and cheap fuel. Also the efficiency of these type of engines is inherently low. In Kansas, about 99.4% of the pumping plants powered by natural gas engines are located in the Northwest, Southwest, and Southcentral regions, which are located within the Ogallala aquifer where the pumping water levels are between 190 to 275 feet (Slogget, 1981).

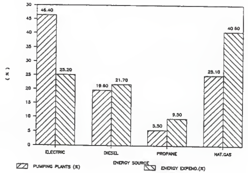

Figure 9. Pumping Plants and Energy Expenditure in the U.S.
Distribution by Fuel Source.
(Adapted from Gilley, 1982)

EFFICIENCY EVALUATION OF PUMPING PLANTS

Purposes of Efficiency Evaluations

The Pumping Plant Performance Rating (PPPR) evaluation is a powerful tool that indicates if a pumping plant is or is not using the fuel efficiently. It doesn't tell, however, which of its components, the pump or the power unit, is causing trouble, if any, and to what degree. In other words, the PPPR is not an indicator of the individual efficiencies of the pump and the power unit. Once these parameters have been determined it is possible to direct repairs, replacement or adjustments to the component(s) that is (are) working inefficiently. In the case of electric-supplied pumping plants, it is known that the only source of problems could be due to the pump if the unit is performing below 100% NPPPC. As a general rule it is assumed that electric motors always work at or very near peak efficiency, if they are loaded between 75% to 125% of rated load. Therefore, the adjustments, repairs or replacements made in order to improve the PPPR will be directed towards the pump. In the case of engine-powered pumping plants the engine efficiency has to be obtained using the procedure discussed in the review of literature. After that, the pump efficiency can be determined. If the pump or the engine or both are below the efficiencies recommended by the NPPPC, then actions will be taken to raise their individual efficiencies up to the Nebraska Standards, or at

least up to the point where they are economically feasible.

Data Collection

The data required to determine pump and power unit efficiencies must include, besides the data necessary to obtain the PPPR, the torque measurement if the pumping plant is powered by internal combustion engines. This last requirement sets a limitation to the quantity of data available to be processed. Only 101 (20.7%) of the pumping plant tests collected that were powered by engines included torque measurements, and 161 (33%) of them were powered by electric motors. Second, the BTU rating necessary to calculate the Input horsepower (IHP) was assumed to be 925,000 BTU/ft^3 for natural gas, 140,000 BTU/gal for diesel, and 92,000 BTU/gal for propane fuels. Nevertheless, the BTU ratings provided by the Northwest Kansas Groundwater Management District, for natural gas fuels, were obtained from two gas companies (Great Plains Electric Co-op, and Northwest Kansas Electric Co-op) which were co-sponsoring the Well Efficiency Testing Program. Since the overall efficiency is the ratio of the useful work (WHP) to the energy input (IHP) then the torque measurements were not necessary to determine these parameters. Thus, all the 486 pumping plant tests were evaluated for this purpose.

Efficiency Overview

The overall, power unit, and pump efficiencies recommended by the Nebraska Criteria are graphically shown in Figure 10. These values of efficiencies do not take into account the pump and electric motor corrections that were subject to all the data applicable. There is no considerable difference, however, between the corrected or uncorrected values with regard to invalidating their use for purposes of comparison. Table 10 gives ranges of theoretical, typical, and average values of overall efficiencies for pumping plants of different fuel sources and considers the variations in overall efficiency due to high and low compression natural gas and propane engines (Longenbaugh, 1983). Finally, Figure 11 presents the average overall efficiency, average power unit efficiency, and average pump efficiency, determined from the data collected. It is noticeable that all the averages computed are below the Nebraska recommendations except for the case of the electric-motor pumping plants, which has an average power unit efficiency slightly higher than recommended. However, all of the average overall efficiencies are concordant with the ranges of average overall values from the field tests tabulated in Table 10.

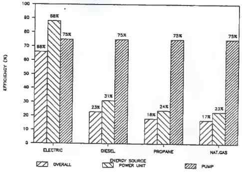

Figure 10. Overall, Power Unit and Pump Efficiency. For Pumping Plants meeting 100% NPPPC. (Source: Schroeder, 1982)

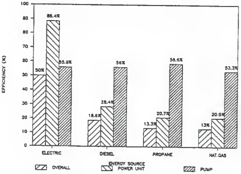

Figure 11. Overall, Power Unit and Pump Efficiency. Average Values from the Tests Collected.

Table 10. Typical values of overall efficiency

Energy Source	Maximum Theoretical (%)	Recommended as acceptable (%)	Average values from field Tests (%)
Electric	72 - 77	65	45 - 55
Diesel	20 - 25	18	13 - 15
Propane	18 - 24	15 - 18	9 - 13
Nat.Gas	18 - 24	15 - 18	9 - 13

Table reproduced from Longenbaugh, 1983.

Overall Efficiency

In the evaluation of overall efficiencies by fuel source, the main problem found was the scarcity of data points for pumping plants powered by propane and diesel engines. For the former, only 17 were counted, and for the latter, only 45. In spite of this, all the data pertaining to diesel and propane units was frequency distributed and the results are shown in Figures 12 and 13, in the respective order.

For propane units, 3 pumping plants exceeded the Nebraska Standard, 2 of them were in the range of 16% to 18% of NPPPC, and the rest were working at or below 16% of NPPPC. For diesel pumping units, only about 27% of them met or exceeded the Nebraska recommendation, and 73% were with overall efficiencies lower than 22%. For electric-motor units, about 26% of the pumping plants tested were operating with overall efficiency higher than 60%, and 72% of the subsample was

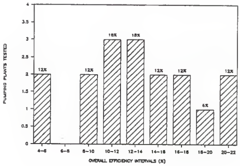

Figure 12. Overall Efficiency Distribution. Pumping Plants with Propane Engines.

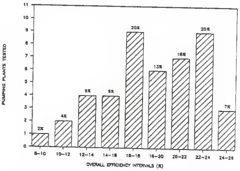

Figure 13. Overall Efficiency Distribution. Pumping Plants with Diesel Engines.

operating below or at 60% (see Figure 14). Finally, only 23% of the natural gas pumping plants were performing with overall efficiency higher than 16% and 67% of them at or below 16% (Figure 15).

The low, high, and average values of the overall efficiency for the four energy sources considered were 17.2%, 79.3%, and 50% for electric-motor units; 8.8%, 25.2%, and 18.6% for diesel units; 5.4%, 21.7%, and 13.3% for propane; and 2.2%, 22.1%, and 13% for natural gas pumping plants (Figure 16). Again, notice that all the average overall efficiencies found are within or higher than the ranges of average overall efficiency from the field tests of Table 10.

Power Unit Efficiency

The average, low, and high values of power unit efficiencies of 262 pumping plant tests collected, which included torque measurements or were of electric type, are shown in Figure 17. Electric motors were found to be the most efficient drivers, followed by diesel, propane, and natural gas engines, in decreasing order. It was not possible to make a generalization of the tendency of efficiency of diesel and propane engines because the scarcity of the data yielded only 5 diesel and 7 propane engines. In each case, however, the individual averages do not depart very much from the Nebraska recommendation. Nebraska recommends 31% efficiency for diesel

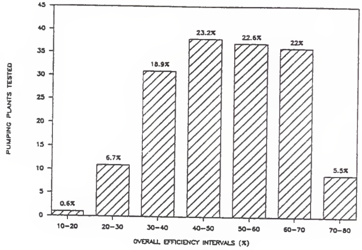

Figure 14. Overall Efficiency Distribution. Pumping Plants with Electric Motors.

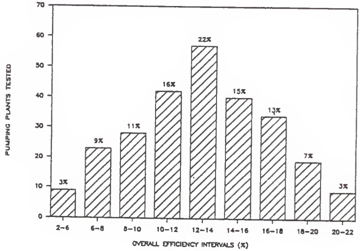

Figure 15. Overall Efficiency Distribution. Pumping Plants with Natural Gas Engines.

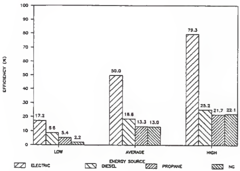

Figure 16. Overall Efficiency.
Extreme and Average Values.

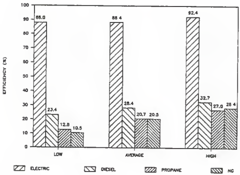

Figure 17. Power Unit Efficiency.
Extreme and Average Values.

and 24% for propane engines, compared with 28.4% and 20.7% average efficiency determined in the present research for both types of power units, respectively. The average efficiency of natural gas engines was 20.5%, or 3.5% below the Nebraska Standard, and the average efficiency of electric motors was 88.4%, or 0.4% higher than the Nebraska Standard. This slight difference is mainly due to the motor correction, a factor not reflected in the Nebraska Criteria.

The frequency distribution of electric motor efficiencies shows that none of the power units of this type were working below the standards as it was previously forecasted (see Figure 18). However, most of the other types of power units were working below the recommended values. About 69% of the natural gas engines were running with efficiencies lower or at 22% (23% is the standard) as shown in Figure 19. In the cases of diesel, and propane engines the scarcity of data did not permit evaluation of the tendency of their efficiencies as can be seen through the distribution histograms of Figures 20 and 21.

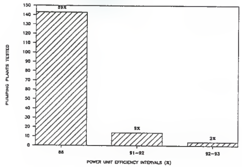

Figure 18. Power Unit Efficiency Distribution.
Electric Motors.

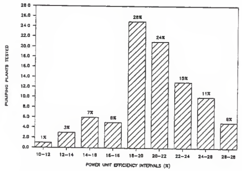

Figure 19. Power Unit Efficiency Distribution.
Natural Gas Engines.

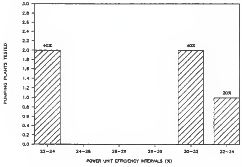

Figure 20. Power Unit Efficiency Distribution. Diesel Engines

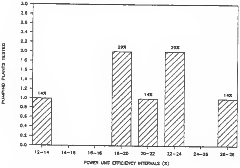

Figure 21. Power Unit Efficiency Distribution. Propane Engines.

Pump Efficiency

In Figure 22 are presented the low, high, and average values of pump efficiency of 262 pumping plants corresponding to the same amount of units which were evaluated for power unit efficiencies. In this case, it is not relevant to make pump efficiency evaluations by energy source as was the case for the power units, because the performance of the pumps is independent of the type of energy used to drive it. In support of this, it is interesting to notice that the latter fact is supported by the averages calculated by fuel source in comparison with the 57% general pump efficiency average. Furthermore, the individual pump efficiency averages by fuel source were not statistically different from each other ($\alpha = 0.05$). Finally, the lowest pump efficiency found was 17.7%, corresponding to a pump powered by a natural gas engine, and the highest 85.8%, corresponding to a pump driven by an electric motor.

On the other hand, about 83% of the pumps were performing below or at 70% efficiency (Nebraska recommends 75%) and 17% of them higher than 70% efficiency (see Figure 23). In the case of pumps driven by electric motors, 77% of them (the total is 161) were operating at or below 70% efficiency while all the electric power units were assumed to be working above or equal to the NPPPC. In the case of pumps driven by diesel engines, all of the pump efficiencies were below the Nebraska

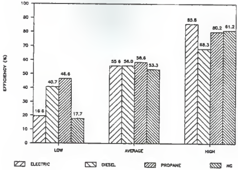

Figure 22. Pump Efficiency.
Extremes and Average values.

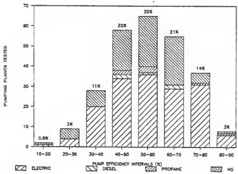

Figure 23. Pump Efficiency Distribution.
Overall and by Energy Source.

standard while only 40% of the corresponding power units were lower than the NPPPC. For pumps powered by natural gas engines, 93% of them were below the NPPPC and 69% of the respective power units were working under the NPPPC. Finally, 71% of the pumps driven by propane engines were below the recommended values, while 80% of the respective engines were with lower efficiencies than the NPPPC (see Table 11). This analysis implies that the definite cause for poor performance of pumping plants powered by electric motors is attached to the pump. For diesel and natural gas pumping units, the major cause for poor performance would logically be the pump, since a larger percentage of the pumps are below the Nebraska standard in comparison with the percentages of power units falling under the NPPPC. For propane pumping plants the inverse is true. In the same sample there are more power units than pumps performing below the Nebraska standards. However, this could be a consequence of the scarce data used for this analysis.

The average pump efficiencies calculated in each year under the period of consideration does not depart very much form the average pump efficiency over the period 1981-88, except for the Years 1981 and 1985 (Table 12). From 1982 to 1984 and from 1986 to 1988 the yearly average pump efficiencies were around 53%, and in 1981 and 1985 the corresponding values were 63.7% and 49.4%. The 1981 average seems to be responsible for the total average of the period

to be as high as 57%.

Table 11. Comparison of Performances of Pumps and Power Units.

Energy Source	Percent of power units less than NPPPC	Percent of pumps less than NPPPC	Most of the problems of poor performance attached to
Electric	None	77	Pump
Diesel	40	100	Pump
Propane	80	71	P.u.
Natural Gas	69	93	Pump
Overall		83	

Table 12. Yearly Average Pump Efficiency.

YEAR OR PERIOD	UNITS TESTED	AVERAGE
1981	51	63.7
1982	20	54.6
1983	37	53.6
1984	33	53.8
1985	40	49.4
1986	59	53.6
1987	4	53.1
1988	18	55.1
81-88	262	55.11

PUMP EFFICIENCY DECREASE WITH AGE

Motivation of the Investigation

The motivation of including an analysis of pump decrease in efficiency with age in this research was born due to the necessity of giving to the model and computer program ICEASE (Irrigation Cost Estimator and System Evaluator) a parameter of yearly pump decline in efficiency (For further information see Williams, 1986). This model, which was developed by the Departments of Agricultural Economics and Agricultural Engineering of Kansas State University in 1985, estimates, in one of its items (option 3), the operating costs associated with changes caused by a falling water table and/or a pump efficiency decline on a yearly basis. The problem is that the annual pump decrease in efficiency is assumed by the user of the program to be, in general, 1% per year, and up to the present time no parameter has been suggested for making the economic evaluation closer to reality. As a consequence, the resultant operating costs will be higher or lower depending on the guess that the user inputs to the computer. Furthermore, there is no way to know how well the assumption of point decline in efficiency per year has been.

Data Collection

The data utilized to make analysis of pump decrease in efficiency with age should contain as minimum requirements, and along with the data necessary to make power unit and pump efficiency evaluations, the year of installation, brand, model, number of stages, speed, and test year of the pump. It is recommended but not strictly necessary that the type of power unit and its rated horse power be included. The pumping plants tests collected with all these requirements were only 43. However, about 96 data points had information of pump efficiency and installation year. Pumping plants powered by electric motors were the major source of information for this investigation. From the 43 pumping plant tests mentioned previously, 39 were electric powered, 2 of them were driven by natural gas engines, and only 1 was of diesel type. The main reason for this is that, in general, the pumping plants powered by engines did not have torque measurements made, and this step is not necessary for those units powered by electric motors for the purpose of determining pump efficiency. Thus, most of the pumping plants collected were falling within the electric-type pumping plants. For these various qualifications, see the appendix (Table 17), in which are presented the data used to make the analysis of pump efficiency decrease with age.

Procedure of the Investigation

First approach: The logarithmic model

a) First Method

For each of the 43 data points, the following steps were made in order to obtain a relation between the decrease in efficiency and the age of the pump:

1.- With the information of pump brand and model it was possible to get the pump performance curves (or characteristic curves) from the manufacturers (for a sample of a performance curve, see Figure 28 in the appendix).

2.- The total dynamic head (TDH) recorded in the pumping plant test was divided by the number of stages of the pump in order to obtain the head that each of the impellers were working against (TDH/STAGE). This step was necessary because the manufacturer's performance curves only gives a relation between the discharge of the pump versus the head of one bowl of the pump.

3.- The discharge of the pump (GPM) from the field test was then used to find the laboratory head of the pump in the characteristic curves. In the same curve is also graphed the field TDH/STAGE that was calculated in step 2. Then the field TDH/STAGE was subtracted from the laboratory TDH/STAGE obtaining what will be called decrease in TDH/STAGE:

$$TDH(decrease) = TDH(lab) - TDH(field) \qquad [17]$$

Where the TDH(decrease) is the decrease in head of a single bowl of a pump during its life of operation.

This step was used to examine the relation existing between the decrease in efficiency and the decline of TDH/STAGE of the pumps which were used for explanations in the second approach.

4.- With the pumping plant test discharge and the characteristic curves is then obtained the laboratory efficiency. This is the efficiency that the pump would have when new. Then the field efficiency is subtracted from the laboratory efficiency obtaining a decrease in efficiency. In mathematical form, the equation was set as follows:

$$EFF(decrease) = EFF(lab) - EFF(field) \qquad [18]$$

Where EFF(decrease) represents the total pump efficiency decline during the period since the pump was installed until the test date.

If the field pump speed in RPM did not coincide with the specifications of the manufacturer's curves, then the laboratory head and efficiency had to be different from what was read in the curves at certain field gallonages. Thus, it was necessary to apply the affinity laws to correct both laboratory head and efficiency.

For small changes in impeller speed the laboratory head at other speed than published in the characteristic curves were made as follows (Jacuzzi Bros):

$$TDH(lab)2 = TDH(lab)1 * (RPM(field) / RPM(design))^2 \quad [19]$$

Where TDH(lab)1 is the laboratory head at the manufacturer's speed design.

TDH(lab)2 is the laboratory head obtained at speeds other than published. This is also the laboratory head that is used in equation [1] for calculating TDH(decrease).

RPM(field) is the pump test speed, and

RPM(design) is the speed specified in the characteristic curves.

In order to determine the laboratory efficiency for impeller speeds other than the specified, the gallonage obtained in the pump test had to be modified using the formula:

$$GPM2 = GPM1 * \frac{RPM(field)}{RPM(design)} \quad [20]$$

Where GPM1 is the discharge of the pump at manufacturer's impeller speed design, and

GPM2 is the discharge of the pumping plant test at other speed than specified.

The laboratory efficiency encountered at the intersection of the GPM2 with the original characteristic curve was then the value assigned for the laboratory efficiency of the pump when the field speed was not coincident with that published

by the pump manufacturers.

The affinity law 2 which is applied when the impeller diameter of the pump is different than that specified in the performance curves was not used in this research since all the pump impellers recorded were coincident with the specifications.

5.- To determine the approximate years of operation of the pumps tested, the year of installation was subtracted from the test date in the following form:

$$\text{PUMP AGE} = (\text{TEST DATE}) - (\text{INSTALLATION DATE}) \quad [21]$$

6.- With the data column EFF(decrease) and PUMP AGE, the following three regression models were used in order to see which of them adapted better to the data:

a) Linear,

b) Exponential, and

c) Logarithmic.

The best regression equation found was the logarithmic fit which is presented in figure 24, and is of the form:

$$\text{EFF(decrease)} = -3.9 + 25.6 * \text{LOG(PUMP AGE)} \quad [22]$$

Where the term EFF(decrease) is the expected pump efficiency decline of a pump that had been working for "PUMP AGE" years, and LOG is a base-10 logarithm.

The regression was statistically significant ($\alpha = 0.05$) and the R-squared was somewhat low (R-square = 0.38, see

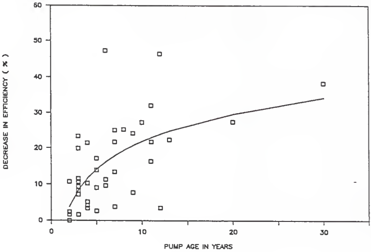

Figure 24. Decrease in Efficiency vs Pump Age. Logarithmic Equation Corresponding the First Approach, First Method. EFF(decrease)=-3.9+25.6*LOG(PUMP AGE)

appendix, Table 18). The low R-squared obtained is justified because of the variation of conditions which the pump may be subject to during its life of operation. It can be noticed that this analysis does not take into account the number of hours of operation of the pumps in a year, information that was not possible to obtain from the data collected and which can be very variable. There may be pumps that only work a few hundred hours annually compared to others that work as much as 5,000 to 6,000 hours per year. In this sense, a pump operating 5,000 hours yearly would make the equivalent work of 5 years if compared with a pump that only works 1,000 hours annually.

Even among pumps working the same amount of time every year, variable conditions may make them have different rates of pump efficiency decrease with age. First, consider that the improper design of wells could cause excessive sand flow to the impellers which will make them wear faster than pumps installed in well designed wells. Therefore, the faster the impellers wear, the faster the efficiency decrease. The quality of water may be the cause for corrosion on the impellers of the pumps and, thus, the cause of premature efficiency decrease of the same. Misalignment of wells can produce bending on the shaft of the pumps inducing extra friction on the connections of the latter and the impellers. This situation creates possibilities of recirculation of water in the impellers and also makes the pump appear with less

efficiency than others that have worked the same amount of time but in normal conditions. In other cases, the installation of the pumps is not adequate and the impellers may be misadjusted. This may be the cause for a 2-year old pump to have an apparent decrease in efficiency similar to a well adjusted 10-yr old pump that works the same amount of hours annually as the first. Finally, the maintenance of pumps differs among farmers and this is information not available for this analysis. It is quite possible that some pumps have been repaired, replaced or adjusted before the pumping plant test had been made. This would make older-repaired pumps appear with lower efficiency decrease rates than newer pumps with low or no maintenance even if the work rate per year is the same for both groups.

b) Second Method

Another method applied to solve this problem was made using all of the 96 data points, which included pump efficiency and year of installation, but not necessarily the brand, rpm, model, and number of stages of the pump. In this case, the values of decrease in efficiency were obtained by subtracting the observed pump efficiencies from the Nebraska Standard:

$$\text{EFF(decrease)} = 75\% - \text{EFF(pump)} \qquad [23]$$

In some cases the actual pump efficiency was found greater than 75% and, thus, the EFF(decrease) had to be set

to zero. However, the zeros' decrease in efficiency were omitted from the analysis unless they corresponded to pumps aging less or equal than 2 years. The reason for this is that it is assumed that when the pump is new there is zero age and zero decrease in efficiency. However, after more than two years some decrease in efficiency has to happen if the pump has been working. The regression equation obtained using this method was (figure 25):

$$EFF(decrease) = -1.4 + 22.14 * LOG(PUMP\ AGE) \qquad [24]$$

And in this case, the regression was statistically significant ($\alpha = 0.05$) and the R-squared was 0.34 (see the appendix, Table 20) which is still lower than the one of the latter fit.

It is interesting to observe that the equations corresponding to the two regressions mentioned are very similar and the difference of the predicted values obtained using either one of the two equations is practically the same. This similitude could be a coincidence but it also could be a hint indicating that it is no longer necessary to follow the tedious steps of the first approach (first method). Instead, similar results could be obtained applying the second method which is easiest and there are more possibilities of including more data in the analysis.

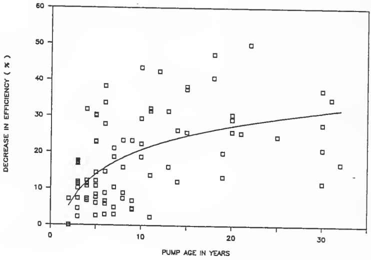

Figure 25. Decrease in Efficiency from 75% NPPPC versus Pump Age. Logarithmic Equation Corresponding to First Approach, Second Method. EFF(decrease)=-1.4+22.14*LOG(pump AGE)

Second Approach: The multilineal Model

The last approach used to find a relation between pump efficiency decrease and time was made using the values of EFF(decrease) and PUMP AGE from the data set of the first approach, and adding three more variables: the total dynamic head (TDH), the number of stages of the pump (STAGE), and the size of the bowls (SIZE) (see appendix, Table 21). Originally, the data set included the discharge of the pump (GPM), the dynamic water level (PWL), the pump output horse power (WHP), and the speed of the pump (RPM). Nevertheless, throughout the regression and correlation analysis it was determined that those variables had very little or no effect on the decrease in efficiency with time, and, consequently, they were omitted from further analysis. The multiple regression equation found was:

$$\begin{aligned} EFF(decrease) = -41.5 &+ 4.5*(SIZE) + 7.1*(STAGE) \\ &- 0.14*(TDH) + 0.46*(AGE) \qquad [25] \end{aligned}$$

In this case, the R-squared was 0.65 and the regression was statistically significant with α=0.05 (see appendix, Table 22).

In this equation the "SIZE" has to be given in inches, the "STAGE" corresponds to the number of bowls, the "TDH" in feet, and the "AGE" in years, in order to obtain a pump efficiency decrease in percent.

On the other hand, it can be noticed that the variables SIZE, STAGE, and AGE are directly proportional to the pump decrease in efficiency, and that the variable TDH is inversely proportional to EFF(decrease). One conceptual problem rises with the augmentation of the efficiency decrease with the increase in the number of stages of the pump. This sets a contradiction with the pump principles which say that the tendency of pumps is to improve their efficiencies as more stages are added up to a certain number after which any addition of stages will not make significant improvements.[1] The inverse proportionality of the TDH regarding the EFF(decrease) can be justified because the last variable mentioned is directly related to the TDH(decrease) in a proportional ascending manner (Figure 26). Therefore, an increase in EFF(decrease) signifies an increase in TDH(decrease), or a decrease in head. In other words, it is expected that if a pump has a decrease in available head per stage, then it also has to have a decrease in efficiency.

[1]This is better understood by looking at the characteristic curve presented in the appendix, Figure 28. In such a curve, if the number of impellers is less or equal than two, then the manufacturers recommend to correct the efficiency of the pump by decreasing 2% for a 1-stage pump and 1% for a 2-stage pump. However, if the number of stages is greater or equal than 3, then the correction is negligible.

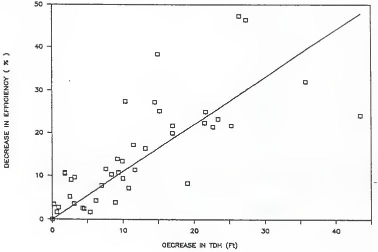

Figure 26. Decrease in Efficiency versus Decrease in TDH.

The Logarithmic vs the Multilineal Model

About the convenience of using the first or the second model, it is necessary to notice that the last regression equation has to afford all the same problems related to the real time of operation of pumps, quality of water, misalignment of wells, bad installation of pumps, etc. Furthermore, the second model has associated the random variations of the pump efficiency decrease to four variables. This could be a source of misleading the real behavior of the EFF(decrease) with age. One example of this can be seen in Figure 24 where the data point {6-yr, 47.3-EFF(decrease)} has an extremely high decrease in pump efficiency in comparison with its time of operation. The most probable causes are associated with the problems that the pump could be subject during its life of operation (hour of operation, misalignment of well, etc.) and not to the physical dimensions of the pump (size, number of bowls) or to the operating conditions (TDH) as it is explained by the model. The major problem that makes this model not adequate is its tendency to justify that pumps with the same physical dimensions (same size, same number of bowls), from which the ones that are working with higher TDH, have the tendency to acquire a smaller efficiency decrease rate. However, the decrease rate does not behave in a logical manner. For instance, Figure 27 has been constructed using the second model for 14-inches, 4-stages pumps, and several

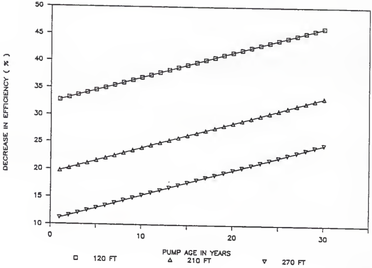

Figure 27. 14-inches, 4-stage Curves.
For TDH from 120 to 270 Feet.

operating TDH. It can be observed that pumps working at 270 ft TDH with 30 years of operation have about 24% decrease in efficiency, while the pumps working at 120 ft TDH have a decrease in efficiency of about 32% at the end of their first year. Furthermore, it is not logical to think a pump could have an EFF(decrease) in the range of 15%, 20%, or even 35% after its first year of operation, no matter its physical dimensions or the TDH it has to work against.

On the other hand, the logarithmic model has the advantage of representing the average decrease in efficiency with time of a typical pump that may subject to all the kinds of problems related to the history of operation of a pump, and without considering its physical dimensions, its operating head, its flow, etc,. Also, the predicted values obtained with this model are not illogical as it can be seen in the calculations of efficiency decrease for pumps working 2 and 30 years which resulted in 3.9% and 34.2% decrease, respectively.

CONCLUSIONS

1.- The average pumping plant performance rating obtained in Kansas for the period 1981-1988 was 74.3% of NPPPC. This average resulted lower than the average pumping plant performance rating estimated for the state of Nebraska for the period 1980-1982 which was 77% of NPPPC. Also, the average excess energy usage determined for Kansas was about the same in comparison with the respective value obtained for Nebraska.

2.- It was concluded that there is no statistical difference in average performance rating among pumping plants powered by any of the four energy sources considered in this research. Typical pumping plants powered by either electric motors, diesel, propane or natural gas engines, have about the same probabilities of attaining similar average performance ratings.

3.- The most popular engine powering pumps in Kansas is the natural gas engine. Electric motors are the second most abundant power unit found, followed by diesel engines, and finally, by propane engines. Gasoline engines are hard to find all around Kansas.

4.- Pumping plants powered by electric motors have the least average cost of money wasted per unit for using extra energy due to poor pumping plant performance. Those powered by natural gas engines have the highest average of money wasted per unit because of excess fuel usage.

5.- Pumping plants powered by electric motors spend less energy per unit than the other fuel sources considered in this research.

6.- The average overall efficiencies for pumping plants powered by any of the four types of power units discussed were lower than the Nebraska recommendations. However, they all were within the ranges of average values from field tests reported by Logenbaugh (1983).

7.- The pumping plants powered by electric motors had the highest average overall efficiency over pumping units driven by any of the other three energy sources studied. This was mainly due to the intrinsic high efficiency of electric motors if compared with the other fuel sources.

8.- Electric motors are the most efficient energy source for irrigation pumps; however, this does not mean that they are the most economical.

9.- The average power unit efficiency for natural gas engines in Kansas was coincident with the corresponding value determined by Schneider (1986), for the Texas High Plains. In addition, the average natural gas engine efficiency determined for Kansas was not statistically different from the respective values reported by Abernathy et al. (1978), and The Cross Section (1980), for New Mexico, and Texas, respectively.

10.- The performance of power units has no effect on the performance of pumps. Therefore, there is no significant difference in average pump efficiency among pumps driven by

either electric motors, diesel, propane, or natural gas engines. Furthermore, there is no significant difference between the individual average of pump efficiencies and the overall pump efficiency average.

11.- According to the statistics of pump and power unit efficiencies, the pumps are the components of the pumping plants which contributes most to poor performance of irrigation pumping units in Kansas.

12.- From the two regression models examined in this research, the logarithmic regression was found more representative of the behavior of the decline in efficiency of pumps with age.

13.- Apparently, there is no significant difference in obtaining the values of pump decrease in efficiency by using either the first or the second methods of the first approach discussed on the corresponding section of this thesis.

14.- The logarithmic equation proposed can be incorporated into the model and computer program ICEASE, in order to estimate the point decline in efficiency of pumps through the years, instead of assuming those values.

RECOMMENDATIONS FOR FUTURE RESEARCH

Although the logarithmic equation can be used to make gross estimations of pump decrease in efficiency with age, some modifications could improve the accuracy of the prediction values given by this model. Perhaps the best approach could be to make a series of tests on the same pump every year, and to repeat this operation with other pumps in different regions of Kansas. However, this would take a long time before any results could be obtained and it also would be very expensive. An alternative would be to make an analysis of those pumping plants that have already been given an efficiency test, and to investigate with the farmers the history of the operation of the pump. In other words, the future researcher should collect pumping plant tests with all the information that was used in the analysis discussed in the first approach of the section "Pump Efficiency Decrease with Age" of this research, plus the following additional information that could be obtained by means of a survey directed to the owners of the pumping plants:

1.- Annual hours of operation of the pumps tested. Also, the farmer should tell if the pump has been working a different amount of hours in different years.

2.- History of the maintenance of the pump. The researcher should inquire if the pump has been repaired, has had some impellers replaced or adjusted, had some bowls changed,etc.

3.- Age of the well and a diagnostic of its actual conditions. For instance, if the pump is discharging sand, then the well screens may be corroded or do not match with the characteristic size of the sand in that sector.

4.- Quality of water in the zone that the pump is working.

5.- Type of irrigation system. It is also important to know whether there has been any shifts from sprinkler to gravity or viceversa during the time of operation of the pump.

6.- The rated HP of the engine or the electric motor that is powering the pump.

It is almost sure that this additional information will improve drastically the equation currently obtained, and will help to explain why some pumps that are almost new have an efficiency decrease rate higher than older pumps.

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APPENDIX

Table 13. Field Form Sheets Used by The Soil Conservation Service of Kansas.

DRAFT
KS-ENG-

IRRIGATION PUMPING PLANT EVALUATION

Name ______________________ County ______________________
Legal Descr. ______________________ Date ______________________

Pumping head:

Depth to Pumping Water Level _____ ft.
Column Head Loss _____ ft.
Discharge Head, Pressure @ Well _____ psi x 2.31 = _____ ft.
Total Dynamic Head = _____ ft.

Well Discharge - Flow Meter:

Propeller Type: Time: _____ Min., _____ Sec., = _____ Min.
Gallons - Stop _____, Gallons - Start _____ =
_____ Total gallons ÷ Time, _____ Min. = _____ gpm

Pitot Tube Type: ID Pipe Dia. _____ in., Differ. Press _____ in., Q = _____ gpm
or Factor _____, Velocity _____ fps, Q = _____ gpm

Energy Use:

Diesel — Time: _____ min., _____ Sec. = _____ Hours
7.1 lbs./gal. — Weight Start _____ lbs. - Weight Stop _____ lbs. =
or — _____ Net Weight Used ÷ _____ lbs./gallon
Propane — ÷ _____ time in hours = _____ gal./hr.
4.25 lbs./gal

Electric — Time_____ min. _____ Sec. = _____ Seconds
3.6 x _____ Disc Revolutions x _____ K_h ÷ _____ Sec. =
_____ KW, _____ Volts, _____ Amps

Natural Gas — Time _____ Min. _____ Sec. = _____ Seconds
3.6 x _____ Dial Capacity x _____ Dial Revolutions ÷
_____ Seconds = _____ x Correction Factor* _____ =
_____ mcf/hr.

*Correction Factor = $\frac{\text{ATM Pressure + Gauge Pressure}}{\text{ATM Pressure + 0.25 psi}}$ = __________
Average ATM Pressure + (14.72 - Elevation Correction) = __________
Elevation Correction = (Elevation in thousand feet x 0.5 psi) = __________
= __________

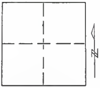
Water Horsepower (Whp) = $\frac{\text{Q(gpm) x Total Dynamic Head (ft.)}}{3960}$
= $\frac{\_\_\_\_\_\ x\ \_\_\_\_\_}{3960}$ = __________ whp

Table 13. (Continuation)

Irrigation Pumping Plant Data

Acres Irrigation by this well ________________ acres
Type of Irrigation System ________________________

Pump Mfg. ____________________ No. of Stages ____
Pump No. _________________ Bowl Setting _________
Pump Shaft Dia. _________ Threads/In. ___________
Year Installed __________ Column Size ___________
Pump Setting _______ ft., Line Shaft Dia. ________
Pump and Impeller Model No. ____________
Impeller Trim Size _____ Tail Pipe Length, ft. _____
Well Driller ______________________ Year Drilled _____
Address _____________________________ Well Depth _____
Drilled Dia. _____ Casing Dia. _____



Location Map
Scale 1" = _____

Power Unit:
Mfg. __________________________ Fuel Type ______ Year Installed _____
Model No. __________ Displacement _______ Serial No. __________
Normal Operating Speed _____ RPM, Continuous Horsepower _____
Gearhead Type ________________ Gearhead Ratio _____

Measured Data:
Pump RPM _______ Driver RPM _______ Static Water Level _______
Cascading Water _______

Torque Cell Readout:
Torque _________ in. lbs. RPM __________ BHP __________

Table 13. (Continuation)

DRAFT
KS-ENG-

PUMPING PLANT PERFORMANCE SUMMARY - NATURAL GAS

Name ______________________

Date ____________________

From Sheet No. 1, Form KS-ENG-

Water Horsepower (Whp) = _____, Fuel Use _____ mcf/hr, Q = _____ gpm
Total Dynamic Head (T.D.H.) = _____ ft, Criteria = 61.7 Whp-hrs/mcf
Energy Factor (E.F.) = 2443 for mcf/hr.

Pumping Plant Performance Rating - Nebraska Standard

Performance = $\frac{\text{Whp}}{\text{Fuel Use}}$ ÷ Criteria x 100 = _______ ÷ 61.7 x 100 = _________ %

or T.D.H. _____ ft. x _____ gpm ÷ Fuel Use _____ mcf/hr ÷ E.F. (2443) = _____ %

Performance Rating - Pump and Engine

Brake Horsepower (Bhp) - measured - torque cell readout = __________

Pump Efficiency* = $\frac{\text{Whp}}{\text{Bhp}}$ x 100 = ———— x 100 = ———— %

Input Horsepower (Ihp) = $\frac{\text{Fuel Use (Cu.Ft./hr.) x BTU content of fuel}}{2545}$

= $\frac{\_\_\_\_ \text{ x } \_\_\_\_}{2545}$ = __________

Thermal Efficiency of Engine* = $\frac{\text{Bhp}}{\text{Ihp}}$ x 100 = ———— x 100 = _________ %

Overall Efficiency = $\frac{\text{Whp}}{\text{Ihp}}$ x 100 = ———— x 100 = _________ %

*Optimum efficiencies should run as follows: Pump - 75-80%
Engine - 24-28%

Table 13. (Continuation)

DRAFT
KS-ENG-

COST ANALYSIS - PUMPING PLANT PERFORMANCE

Name ______________________

Date ________________

Nebraska Criteria:

Excess Fuel (______________) Used Annually

Excess Fuel Cost/Hr. = $\frac{100 - \text{Perfor. Rating (\%)}}{100}$ x Energy Use Rate =

$\frac{100 - \_\_\_\_}{100}$ x ______ = ______ x ______ Fuel Cost = __________

Annual Savings Possible = (Annual Pumping Hours) x (Excess Fuel Cost/Hr.)

= _______ x _______ = __________

Reduce Pumping Costs by Improving Pump Efficiency from _______ to _______

$\frac{\text{Present Pump Effic.}}{\text{Improved Pump Effic.}}$ x 100 = $\frac{\_\_\_\_}{\_\_\_\_}$ x 100 = __________ Adjusted Percentage

Annual Fuel Cost = ______ Fuel Use/Hr. x _______ Fuel Cost/Unit

x ________ Annual Pumping Hours = ___________

Savings = (100 - Adjusted Percentage) ÷ 100 x Annual Fuel Cost

= (100 - ________) ÷ 100 x ________ = __________

Reduce Pumping Costs by Improving Engine Efficiency from _______ to _______

$\frac{\text{Present Engine Effic.}}{\text{Improved Engine Effic.}}$ x 100 = $\frac{\_\_\_\_}{\_\_\_\_}$ x 100 = __________ Adjusted Percentage

Adjusted Fuel Use Rate = Original Use Rate x Adjusted Percentage ÷ 100

_________ x _________ ÷ 100 = __________

Savings = (Original Use Rate - Adjusted Use Rate) x Fuel Cost/Unit

_________ - _________ x _________

= _________/Hr. x Annual Pumping Hrs. _________ = __________

Table 14. Field Form Sheets Used by KSU Agricultural Engineering Department.

Kansas State University
Irrigation Pumping Plant Evaluation
Test No. 1

Name Sam Kelsey (Neiswonger) Date 7-84 County Shawnee

Pump	Gear Head	Driver
Type ___	Mfg. ___	Type Electric
Mfg. ___	Ser. No. ___	Mfg. ___
Ser. No. ___	Ratio ___	Ser. No. ___
Size ___ Stages ___	Hp ___ Speed ___	Size ___ Speed ___

Pump RPM 1363 Driver RPM 1786 Torque ft-lbs. ___
Static Water Level 25.0 ft. Dynamic Water Level 29.0 ft.
Pumping Pressure 1.8 psi x 2.31 = 4.16 ft. head
Remarks ___ Total Head = 33.2 ft. head
Pipe Outside Diameter 8.7 Wall Thickness .13
Inside Diameter 8.44 O.D. - 2 W.T.

Collins Flow Meter

Setting Pos.	Right		Left	
1 3/4	5.88	5.64	5.63	5.51
3.0	5.4	5.48	5.06	4.79
3 7/8	5.0	4.97	3.91	3.96
Center line				

Ave. Vel. 5.1 x 2.45 x $(I.D.)^2$ = 890 GPM

Venturi Meter

Gallons ___ / Time ___ = ___ GPM

Eagle Eye Flow Meter

Pipe I.D. ___ Inches Water ___ = ___ GPM

Energy Use

Diesel: weight/500 ml ___ lbs. x 7.57 ___ lbs./gal
(Neb. Std. uses 7.1 lbs/gal)
Pounds Used ___ Time ___ min ___ sec
lbs/hr ___ / ___ lbs/gal = ___ gal/hr

Propane: (4.25 lbs/gal)
Pounds Used ___ Time ___ min ___ sec
lbs/hr ___ / ___ lbs/gal = ___ gal/hr

Electric: Volts 1-2 ___ 2-3 ___ 3-4 ___ Amps 1 41.9 2 38.9 3 41.7
Time ___ min ___ sec = ___ sec
3.6 x ___ Disc Rev. x ___ Kh / ___ sec = 13 Kw

Table 14. (continuation)

<u>Natural Gas:</u> Time ______ min _____ sec = _____ sec
3.6 x ______ Dial Cap. x __________ Dial Rev. / __________ sec
= ____________mcf/hr x _________ Corr. Factor = _________ mcf/hr

Corr. Factor =(Bar. Press + ______ psi gas press)/ (Bar. Press + .25) =
= _______________

Bar Press = 14.7 psi - (0.5 x Elev. / 1000) = ___________

<u>Performance Rating</u>

Pumping Plant
<u>33.2</u>ft. Head x <u>890</u> GPM / 3960 = <u>7.46</u> whp /
Fuel Use <u>13</u> /hr = <u>.57</u> Performance / <u>.885</u> Criteria =
<u>64</u> % Performance Rating

Engine
_____RPM x _____ Torque ft-lbs / 5252 = ____________ hp /
Fuel Use _______/hr = _______Performance / Criteria =
_________% Performance Rating

Pump Efficiency IN Power

Power <u>7.46</u> whp / <u>(13/.746)</u> hp x 100 = <u>43</u> %

Engine Efficiency

______ hp / ________ hp-hr/unit x 100 = _________%

Criteria

Source	hp hr/unit	whp hr/unit	Btu/unit	hp hr/unit
Diesel	16.66/gal	12.5/gal	140,000/gal	55.01/gal
Gasoline	11.50/gal	8.66/gal	124,000/gal	48.72/gal
Propane	9.20/gal	6.89/gal	92,000/gal	36.15/gal
Natural Gas	82.20/mcf	61.7/mcf	925,000/mcf	363.46/mcf
Electric	1.18/kwh	0.855/kwh	________	1.341/kwh

<u>Comments:</u>

Table 15. Field Form Sheets Used by SERVI-TECH.

servi tech

Irrigation Pumping Plant Analysis And Recommendations

Test No. 53

Name ____________ Location ____________ Date ____________

Operating conditions before adjustments

Pumping water level ____________ ft.

Operating pressure ____________ psi

Operating flow-rate ____________ GPM

Power requirement ____________ Whp-hr

Ideal Engine Size ____________ Bhp, Cont.

Rating ______% of the Nebraska Standard

Ac-in/hr ____________

Hr/ac-ft ____________

Fuel/hr ____________

Fuel cost ____________

Hr/ac-ft x fuel/hr x fuel cost = $ /ac-ft

_____ x _____ x _____ = _____

$/ac-in

= _____

Operating conditions following adjustment

Pumping water level ____________ ft.

Operating pressure ____________ psi.

Operating flow-rate ____________ GPM

Power requirement ____________ Whp-hr

Rating ______% of the Nebraska Standard

Ac-in/hr ____________

Hr/ac-ft ____________

Fuel/hr ____________

Fuel cost ____________

Hr/ac-ft x fuel/hr x fuel cost = $ /ac-ft

_____ x _____ x _____ = _____

$/ac-in

= _____

Calculated fuel savings

______ per acre-foot X ______ acres = ______ per 12" of water

= ______ per year

Potential savings if brought up to the Nebraska Standard ____________ per 12" water

____________ per year

Static water level ____________ Cascading water encountered at ____________

Remarks and Recommendations

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Table 15. (Continuation)

"A"

Name ______________________ Test # E-3 __________

Conditions following adjustment

Power rpm __________ Pump rpm __________ Flow rate __________ GPM

Total Head

Discharge head psi = ft + Lift ft + Elevation ft + Friction ft = Total head ft

____ = ______ + ______ + ______ + ______ = ______

Fuel Consumption

Fuel Type: Diesel or Propane

Start lb − Weight Stop lb = Net lb   Time min : sec = hr   lb/hr ÷ Fuel Consumption lb/gal = gal/hr

____ − ______ = ______ ____ : ______ = ______ ______ ÷ ______ = ______

Fuel Type: Natural Gas

psi at meter __________ Cu. ft. used __________

Correction factor __________ Cu. ft. ÷ hr x c.f. = Cu. ft./hr.

min : sec = hr ______ ÷ ______ x ______ = ______

____ : ______ = ______

Fuel Type: Electric

Kw = $\frac{3600 \times \text{Disc Rev} \times \text{PKh}}{\text{sec} \times 1000}$ Kw = $\frac{\text{\_\_\_\_ x \_\_\_\_ x \_\_\_\_}}{\text{x}}$

Evaluation

Total hd x GPM ÷ 3960 = WHP ÷ fuel/hr = WHP/ __________

______ x ______ ÷ ______ = ______ ______ ÷ ______ = ______

WHP/ ______ ÷ Nebr. Standard WHP/ ______ = Rating % of Nebraska Standard

___/ ______ ÷ ______ = ______ %

1978 — 532

Table 15. (Continuation)

Farmer Name ____________ Well Location ____________ Test No. ____________

____________ Inside dia. ____________ SWL ____________ RPM

____________ Radius ____________ PWL ____________ PWL

Measurement Locations

	R	1/R	L	1/L
6 - (____ X 316) = ______				
6 - (____ X 547) = ______				
6 - (____ X 707) = ______				
6 - (____ X 837) = ______				
6 - (____ X 949) = ______				

Time ____ Min ____ Sec ____ Average velocity ____

Nat. Gas ____ PSI ____ Cu Ft. ____ Elect. ____ K_h ____ CTR

Diesel or L.P ____ PTR ____ Rev.

Start ____ lb - Stop ____ lb = Net ____ lb

Pipe area = $\frac{\_\_ X \_\_ X 3.14}{144}$ = ____ Ft^2 Output = ____ X ____ X ____ = ____

Pump Adjustment

____ Shaft dia ____ Shaft length ____ Threads per inch

____ Ft X ____ lb/Ft. = ____ Total downthrust (lbs.)

____ in/100 Ft. X ____ 100 Ft = ____ Inches of shaft elongation

____ in/ ____ in per turn = ____ Turns of adjusting nut

RETEST ____ PWL ____ RPM ____ PSI

Location	R	1/R	L	1/L
1. ______				
2. ______				
3. ______				
4. ______				
5. ______				

Time ____ Min ____ Sec ____ Average velocity ____

Nat Gas ____ PSI ____ Cu Ft ____ Elect. ____ K_h ____ CTR

Diesel or L.P ____ PTR ____ Rev.

Start ____ lb -Stop ____ lb = Net ____ lb

Pipe area = $\frac{\_\_ X \_\_ X 3.14}{144}$ = ____ Ft^2 Output = ____ X ____ X ____ = ____

Table 16. Field Form Sheets Used by the Northwest Kansas Groundwater Management District.

PUMP PLANT EFFICIENCY TEST AFTER PUMP REPAIR

NAME: KEITH APTERBURN WELL LOCATION: SE SE NW 24-6-37

Engine

Manufacturer and Model: CHRYSLER 413

Continuous Duty Rating: 97 HP @ 2347 RPM

Fuel Type: N. GAS

Drive

Manufacturer and Model: AMARILLO S 100

Type: RIGHT ANGLE

Drive Ratio: 4:3

Rating: 100 HP @ 1760 RPM

Pump

Manufacturer and Model: WESTERN LAND ROLLER 12 BH

Number of Bowls: 5

Bowl Diameter: 12

Impeller Size: 12

Pump Setting: 280'

Pump Plant Test Data

Discharge Rate: 953 GPM

Discharge Pressure: 3 PSI

Pumping Level: 235 FT

Estimated Friction Loss: 11-5 FT

Engine Power Output: 80 HP @ 2093 RPM

Fuel Use: .893 Gallons or MCF Per Hour

Fuel BTU Rating: 960,000 BTU Per Gallon or MCF

FUEL Cost: $2.1954 Per Gallon or MCF

Table 16. (continuation)

CALCULATION SHEET

Total Dynamic Head (TDH)

TDH = 235 FT(lift) + 11.5 FT (Friction Loss) + 3 PSI (pressure) X 2.31

TDH = 235 + 11.5 + 6.93 = 253.4 FT

Water Horsepower (WHP) Requirements

$$\text{WHP} = \frac{953 \text{ GPM (pumping rate)} \times 253.4 \text{ FT (TDH)}}{3960} = 61.0 \text{ HP}$$

Pump Efficiency

$$\text{Pump Efficiency} = \frac{61.0 \text{ HP (WHP)}}{80.0 \text{ HP (Meas. HP)}} \times 100 = 76.3\ \%$$

Engine Efficiency

$$\text{Engine Eff.} = \frac{80 \text{ HP (measured HP)} \times 2545.1}{.893 \text{ Gal. or MCF per hour (fuel use)} \times \text{[illegible] BTU per gal. or MCF (fuel rate)}} \times 100$$

$$= 23.8\ \%$$

Pump Plont Performance

$$\text{Pump Plont Perf.} = \frac{61 \text{ HP (WHP)}}{.893 \text{ Gal or MCF per hour (fuel use)}} = 68.31 \text{ WHP hours per gal or MCF}$$

Nebraska Performance Criteria (NPC)

Base NPC = 64.03 WHP-hours per gallon or MCF

Adj. NPC = 64.03 WHP-hours per gallon or MCF (baseNPC) X 1.07 (pump correction factor)

= 68.51 WHP-hours per gallon or MCF

Performance Rating

$$\text{Perf. Rating} = \frac{68.31 \text{ WHP-hours per gal or MCF (pump plant perf.)}}{68.51 \text{ WHP-hours per gallon or MCF (adj. NPC)}} \times 100 = 99.7\ \% \text{ NPC}$$

Excess Fuel Use

$$\text{Excess Fuel} = \left(1 - \frac{99.7\ \%\text{(perf. rating)}}{100}\right) \times .893 \text{ Gal or MCF per hour (fuel use)} = .003 \text{ gal or MCF per hour}$$

Cost of Excess Fuel Use

Cost = .003 gal or MCF per hour (excess fuel) X \$2.1954 per gal or MCF (fuel cost) = \$ .01 per hour

Table 17. Data Used to Make Analysis of Pump Decrease in Efficiency with Age. First Approach, First Method.

ID NUMBER	BRAND	MODEL	STAGES	RPM	TDH/ STGE	LAB TDH	PUMP EFF	LAB EFF	PUMP AGE	DELTA TDH	DELTA EFF
TEC-35	Johnston	12 GMC9	6	1760	65.6	65.6	82.5	82.5	2	0.0	0.0
SCS-9	Johnston	12 ENC	6	1463	55.9	55.9	81.2	81.2	2	0.0	0.0
TEC-36	Johnston	12 GMC9	6	1760	67.4	68.0	81.3	83.0	2	0.6	1.7
TEC-38	Johnston	12 EMC9	5	1760	77.5	82.0	78.6	81.0	2	4.5	2.4
TEC-58	Western LR	12 CM	4	1770	48.6	58.0	67.8	78.5	2	9.4	10.7
TEC-42	Johnston	12 EMC	3	1760	78.6	84.0	79.3	81.0	3	5.4	1.7
TEC-44	Peerless	12 MB	4	1760	55.2	66.0	63.7	71.0	3	10.8	7.3
TEC-41	Johnston	12 EMC	4	1760	62.9	82.0	72.7	81.0	3	19.1	8.3
TEC-48	Western LR	12 CH	3	1760	53.0	63.0	67.6	77.0	3	10.0	9.4
TEC-2	Peerless	12 MB-3	3	1700	62.2	64.0	63.5	74.0	3	1.8	10.5
TEC-15	Peerless	12 MB	4	1760	52.2	54.0	70.4	81.0	3	1.8	10.6
TEC-16	Peerless	12 MB	4	1760	48.9	56.5	70.5	82.0	3	7.6	11.5
TEC-40	Johnston	12 EMC9	4	1760	57.0	74.0	58.1	78.0	3	17.0	19.9
TEC-4	Jacuzzi	12 LS 9	3	1760	44.6	68.0	57.7	81.0	3	23.4	23.3
TEC-3	Western LR	12 CM	4	1760	54.8	55.0	76.5	80.0	4	0.2	3.5
TEC-14	Peerless	12 MB-3	3	1800	61.8	68.0	68.2	72.5	4	6.2	4.3
TEC-33	Peerless	12 MB	3	1760	64.5	67.0	62.8	68.0	4	2.5	5.2
TEC-19	Western LR	12 CM	4	1760	40.6	49.0	67.7	78.0	4	8.4	10.3
TEC-46	Peerless	14 LC	1	1760	67.3	90.0	63.6	85.0	4	22.7	21.4
TEC-18	Berkeley	10 O4H	4	1800	45.9	50.2	72.4	75.0	5	4.3	2.6
TEC-12	Peerless	12 MB	3	1800	65.8	66.7	64.2	67.0	5	0.9	2.8
TEC-20	Western LR	12 CM	4	1760	45.3	48.0	68.9	78.0	5	2.7	9.1
TEC-43	Berkeley	10 O4H	4	1760	42.8	52.0	52.1	66.0	5	9.2	13.9
TEC-25	Western LR	12 CM	3	1760	43.5	55.0	62.8	80.0	5	11.5	17.2
TEC-17	Berkeley	10 K3H	4	1760	45.3	48.5	68.4	78.0	6	3.2	9.6
TEC-61	Western LR	12 CH	4	1780	41.0	52.7	66.2	77.5	6	11.7	11.3
KSU-29	Western LR	10 DH	4	1785	9.6	36.0	36.7	84.0	6	26.4	47.3
TEC-131	Western LR	10 DH	2	1780	32.1	41.0	70.1	74.0	7	8.9	3.9
TEC-57	Western LR	12 CM	3	1760	49.6	59.5	64.6	78.0	7	9.9	13.4
SCS-3	Johnston	14 AC	3	1636	67.0	84.0	56.3	78.0	7	17.0	21.7
TEC-34	Berkeley	10 KBM	7	1850	23.3	45.0	54.0	79.0	7	21.7	25.0
TEC-27	Western LR	12 CM	4	1760	45.8	61.0	51.8	77.0	8	15.2	25.2
KSU-72	Western LR	12 CH	3	1467	38.0	45.0	68.3	76.0	9	7.0	7.7
KSU-27	Western LR	12 BH	2	1780	23.0	66.5	51.9	76.0	9	43.5	24.1
KSU-71	Western LR	10 CH	7	1781	34.5	49.0	52.8	80.0	10	14.5	27.2
SCS-43	Western LR	10 CM	3	1770	37.9	51.0	43.6	60.0	11	13.1	16.4
TEC-59	Berkeley	12 K4MH	2	1780	34.7	60.0	61.3	83.0	11	25.3	21.7
KSU-57	Western LR	12 BH	1	1779	28.2	64.0	43.0	75.0	11	35.8	32.0
TEC-32	Layne Bowler	10 JKM	2	1800	28.4	31.5	74.9	78.5	12	3.1	3.6
KSU-61	Western LR	10 CCH	4	1774	13.6	41.0	32.6	79.0	12	27.4	46.4
SCS-22	Johnston	14 AC	2	1639	74.5	96.0	43.6	66.0	13	21.5	22.4
KSU-28	Western LR	10 DM	4	1784	8.6	19.0	44.5	72.0	20	10.4	27.5
KSU-56	Western LR	12 BH	2	1260	10.6	25.5	37.7	76.0	30	14.9	38.3

Table 18. Results of Regression Analysis. First Approach, First Method.

DEPENDENT VARIABLE : EFF(decrease)

INDEPENDENT VARIABLE : PUMP AGE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	2269.05	2269.04	25.217	0.0001
ERROR	41	3689.27	89.98		
C TOTAL	42	5958.32			

ROOT MSE	9.486	R-SQUARE	0.3808
DEP MEAN	14.705	ADJ R-SQ	0.3657
C.V.	64.509		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > [T[
INTERCEPT	1	-3.8991	3.9771	-0.980	0.3326
LOG(PUMP AGE)	1	25.8007	5.1379	5.022	0.0001

EFF(decrease) = $-3.9 + 25.8 * LOG_{10}$ (PUMP AGE)

Table 19. Data Used to Make Analysis of Decrease in Efficiency with Age. First Approach, Second Method.

ID NUMBER	PUMP BRAND	ENERGY SOURCE	PUMP EFF (%)	PUMP AGE (years)	DELTA EFF (%)
KSU-22	Western LR	E	55.1	19	19.9
KSU-23	Western LR	E	49.7	21	25.3
KSU-26	Western LR	NG	25.1	22	49.9
KSU-27	Western LR	E	51.9	9	23.1
KSU-28	Western LR	E	44.5	20	30.5
KSU-29	Western LR	E	36.7	6	38.3
KSU-36	Western LR	E	56.3	10	18.7
KSU-38	Western LR	P	54.1	30	20.9
KSU-39	Leyne Bowler	P	47.2	30	27.8
KSU-40	Western LR	E	50.7	25	24.3
KSU-42	Western LR	E	49.3	20	25.7
KSU-50	Leyne Bowler	E	37.5	15	37.5
KSU-52	Western LR	E	70.6	9	4.4
KSU-53	Western LR	E	42.9	11	32.1
KSU-56	Western LR	E	37.7	30	37.3
KSU-57	Western LR	E	43.0	11	32.0
KSU-59	Western LR	E	63.0	14	12.0
KSU-61	Western LR	E	32.6	12	42.4
KSU-65	Verti-Line	E	40.2	31	34.8
KSU-66	Leyne Bowler	E	58.0	32	17.0
KSU-67	Verti-Line	E	63.3	30	11.7
KSU-68	Western LR	E	72.7	11	2.3
KSU-71	Western LR	E	52.8	10	22.2
KSU-72	Western LR	D	68.3	9	6.7
SCS-10	Worthington	NG	49.5	15	25.5
SCS-11	Worthington	NG	27.8	18	47.2
SCS-15	Teit A&C	NG	78.4	4	
SCS-19	Leyne-Bowler	NG	43.2	4	31.8
SCS-22	Johnston	NG	43.6	13	31.4
SCS-23	Johnston	NG	58.0	3	17.0
SCS-25	Verti-Line	NG	34.3	18	40.7
SCS-26	Peerless	E	70.4	9	4.6
SCS-27	Layne-Bowler	NG	31.6	10	43.4
SCS-3	Johnston	NG	56.3	7	18.7
SCS-32		NG	61.7	19	13.3
SCS-36	Simmons	NG	45.8	20	29.2
SCS-41	Verti-Line	NG	57.4	3	17.6
SCS-42	Western LR	E	45.7	10	29.3
SCS-43	Western LR	E	43.6	11	31.4
SCS-8	Verti-Line	NG	36.7	15	38.3
SCS-9	Johnston	NG	81.2	2	0.0
TEC-10	Worthington	E	69.1	6	5.9
TEC-11	Western LR	E	44.7	5	30.3
TEC-12	Peerless	E	64.2	5	10.8

Table 19. (Continuation)

ID NUMBER	PUMP BRAND	ENERGY SOURCE	PUMP EFF (%)	PUMP AGE (years)	DELTA EFF (%)
TEC-13	Peerless	E	79.2	5	
TEC-131	Western LR	E	70.1	7	4.9
TEC-14	Peerless	E	68.2	4	6.8
TEC-15	Peerless	E	70.4	3	4.6
TEC-16	Peerless	E	70.5	3	4.5
TEC-17	Berkeley	E	68.4	6	6.6
TEC-18	Berkeley	E	72.4	5	2.6
TEC-19	Western LR	E	67.7	4	7.3
TEC-2	Peerless	E	63.5	3	11.5
TEC-20	Western LR	E	68.9	5	6.1
TEC-21	Peerless	E	60.3	6	14.7
TEC-22	Worthington	E	66.6	5	8.4
TEC-23	Fairbanks Morse	E	60.5	5	14.5
TEC-24	Johnston	E	44.9	5	30.1
TEC-25	Western LR	E	62.8	5	12.2
TEC-26	Western LR	E	52.3	5	22.7
TEC-27	Western LR	E	51.8	8	23.2
TEC-28	Johnston	E	72.1	6	2.9
TEC-3	Western LR	E	76.5	4	
TEC-30	Western LR	E	66.1	8	8.9
TEC-31	Goulds	E	41.4	6	33.6
TEC-32	Leyne Bowler	E	74.9	12	0.1
TEC-33	Peerless	E	62.8	4	12.2
TEC-34	Berkeley	E	54.0	7	21.0
TEC-35	Johnston	E	82.5	2	0.0
TEC-36	Johnston	E	81.3	2	0.0
TEC-37	Johnston	E	81.1	2	0.0
TEC-38	Johnston	E	78.6	2	0.0
TEC-39	Johnston	E	64.2	4	10.8
TEC-4	Jecuzzi	E	57.7	3	17.3
TEC-40	Johnston	E	58.1	3	16.9
TEC-41	Johnston	E	72.7	3	2.3
TEC-42	Johnston	E	79.3	3	
TEC-43	Berkeley	E	52.1	5	22.9
TEC-44	Peerless	E	63.7	3	11.3
TEC-45	Peerless	E	63.1	3	11.9
TEC-46	Peerless	E	63.6	4	11.4
TEC-47	Teit A&C	E	48.9	14	26.1
TEC-48	Western LR	E	67.6	3	7.4
TEC-49	Western LR	E	67.3	5	7.7
TEC-5	Layne & Bowler	E	72.0	7	3.0
TEC-54	Goulds	E	59.1	8	15.9
TEC-55	Goulds	E	67.7	8	7.3
TEC-56		E	64.9	3	10.1
TEC-57	Western LR	E	64.6	7	10.4

Table 19. (Continuation)

ID NUMBER	PUMP BRAND	ENERGY SOURCE	PUMP EFF (%)	PUMP AGE (years)	DELTA EFF (%)
TEC-58	Western LR	E	67.8	2	7.2
TEC-59	Berkeley	E	61.3	11	13.7
TEC-6	Layne & Bowler	E	80.9	13	
TEC-61	Western LR	E	66.2	6	8.8
TEC-7	Layne & Bowler	E	58.9	13	16.1
TEC-8	Berkeley	E	47.2	6	27.8
TEC-9	Worthington	E	68.5	6	6.5

Table 20. Results of Regression Analysis. First Approach, Second Method.

DEPENDENT VARIABLE : EFF(decrease)

INDEPENDENT VARIABLE : PUMP AGE

INTERCEPT = -1.404
SLOPE = 22.140

NUMBER OF OBSERVATIONS = 90
SS TOTAL = 13910
R-SQUARE = 0.3392
ADJ R-SQUARE = 0.3161
F(1,88) = 45.16
F(1,88,0.05) = 3.92

$$EFF(DECREASE) = -1.4 + 22.14 * LOG_{10} (PUMP AGE)$$

Table 21. Data Used to Make Analysis of Pump Decrease in Efficiency with Age. Second Approach.

ID NUMBER	PUMP BRAND	ENERGY SOURCE	BOWL SIZE	No. OF STAGES	TDH (Feet)	PUMP AGE	DELTA EFF
TEC-35	Johnston	E	12	6	393.9	2	0.0
SCS-9	Johnston	NG	12	6	335.3	2	0.0
TEC-36	Johnston	E	12	6	404.1	2	1.7
TEC-38	Johnston	E	12	5	387.5	2	2.4
TEC-58	Western LR	E	12	4	194.5	2	10.7
TEC-42	Johnston	E	12	3	235.9	3	1.7
TEC-44	Peerless	E	12	4	220.8	3	7.3
TEC-41	Johnston	E	12	4	251.8	3	8.3
TEC-48	Western LR	E	12	3	159.1	3	9.4
TEC-2	Peerless	E	12	3	186.6	3	10.5
TEC-15	Peerless	E	12	4	208.7	3	10.6
TEC-16	Peerless	E	12	4	195.6	3	11.5
TEC-40	Johnston	E	12	4	228.2	3	19.9
TEC-4	Jacuzzi	E	12	3	133.7	3	23.3
TEC-3	Western LR	E	12	4	219.0	4	3.5
TEC-14	Peerless	E	12	3	185.5	4	4.3
TEC-33	Peerless	E	12	3	193.5	4	5.2
TEC-19	Western LR	E	12	4	162.4	4	10.3
TEC-46	Peerless	E	14	1	67.3	4	21.4
TEC-18	Berkeley	E	10	4	183.5	5	2.6
TEC-12	Peerless	E	12	3	197.4	5	2.8
TEC-20	Western LR	E	12	4	181.2	5	9.1
TEC-43	Berkeley	E	10	4	171.1	5	13.9
TEC-25	Western LR	E	12	3	130.5	5	17.2
TEC-17	Berkeley	E	10	4	181.3	6	9.6
TEC-61	Western LR	E	12	4	164.0	6	11.3
KSU-29	Western LR	E	10	4	38.2	6	47.3
TEC-131	Western LR	E	10	2	64.1	7	3.9
TEC-57	Western LR	E	12	3	148.7	7	13.4
SCS-3	Johnston	NG	14	3	201.0	7	21.7
TEC-34	Berkeley	E	10	7	163.4	7	25.0
TEC-27	Western LR	E	12	4	183.2	8	25.2
KSU-72	Western LR	D	12	3	114.0	9	7.7
KSU-27	Western LR	E	12	2	46.0	9	24.1
KSU-71	Western LR	E	10	7	241.4	10	27.2
SCS-43	Western LR	E	10	3	113.6	11	16.4
TEC-59	Berkeley	E	12	2	69.4	11	21.7
KSU-57	Western LR	E	12	1	28.2	11	32.0
TEC-32	Layne Bowler	E	10	2	56.8	12	3.6
KSU-61	Western LR	E	10	4	54.4	12	46.4
SCS-22	Johnston	NG	14	2	149.0	13	22.4
KSU-28	Western LR	E	10	4	34.5	20	27.5
KSU-56	Western LR	E	12	2	21.2	30	38.3

Table 22. Results of Regression Analysis.
Second Approach.

DEPENDENT VARIABLE : EFF(decrease)

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	3872.53	968.13	17.638	0.0001
ERROR	38	2085.79	54.89		
C TOTAL	42	5958.32			

ROOT MSE	7.409	R-SQUARE	0.6499
DEP MEAN	14.705	ADJ R-SQ	0.6131
C.V.	50.384		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0
INTERCEPT	1	-41.4717	18.3836	-2.256
SIZE	1	4.4636	1.4342	3.112
STAGES	1	7.1150	1.5489	4.594
TDH	1	-0.1436	0.0248	-5.790
PUMP AGE	1	0.4646	0.2817	1.649

PROB > [T[
0.0299
0.0035
0.0001
0.0001
0.1074

EFF(decrease) = -41.5 + 4.5*(SIZE) + 7.11*(STAGES)
- 0.14*(TDH) + 0.46*(PUMP AGE)

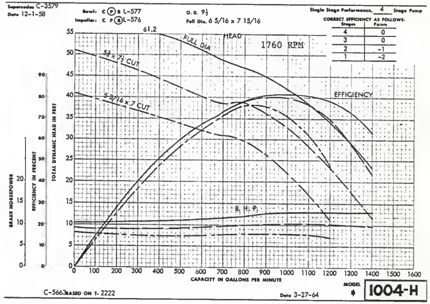

Figure 28. Pump Characteristic Curve Corresponding to Data Point TEC-18. (Source: Berkeley Pump Company).

IRRIGATION PUMPING PLANT PERFORMANCE
AND
PUMP EFFICIENCY DECREASE WITH AGE

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ABSTRACT

Four hundred eighty six pumping plant tests made in Kansas during the period 1981 to 1988 were collected and processed in order to determine their performance rating, excess fuel usage, energy expenditure, and overall efficiency. From the total tests recorded, 262 pumping plant tests were evaluated in terms of power unit and pump efficiency. All the evaluations were made using as a reference the Nebraska Pumping Plant Performance Criteria. Finally, about 96 tests were taken from the total sample with the purpose to analyze the relation between pump efficiency decrease and pump age.

The average pumping plant performance was 74.3% of NPPPC. About 14.2% of the pumping plants met or exceeded the NPPPC.

The average excess energy usage was about 30.5%. Assuming that the average period of pumping water for irrigation is 2000 hours a year, the total average energy wasted by a typical electric pumping plant in a typical year of the present decade was about 69.10 millions KW. For engine-powered pumping plants, the figures of wasted fuel were 7.302 million gallons for diesel units, 6.365 million gallons for propane units, and 7.649 million mcf (thousands of cubic feet) for natural gas units. As a consequence, an estimated cost of $39.4 million is paid for extra fuel usage in a typical year during the period 1981-1988.

The average total energy expenditure for pumping irrigation water in a typical year was estimated in 1.86

million Mega Joules per hour (MJ/h). The greatest consumer of energy is the natural gas engine with about 14.4 million MJ/h, followed by diesel engines with 2.48 million MJ/h. Pumping plants powered by propane engines and electric motors were averaging about 1.04 and 0.566 MJ/h, respectively.

Average overall efficiencies for pumping plants powered by electric motors, diesel, propane and natural gas engines were 50%, 18.6%, 13.3%, and 13%, respectively. Respectively and in the same order, the average power unit efficiencies were 88.4%, 28.4%, 20.7%, and 20.5%. About 83% of the pumps tested were with efficiencies below or at 70% of Nebraska recommendations. The average pump efficiency was 57% of NPPPC.

The relation between pump age and pump efficiency decrease was modeled with the logarithmic equations:

EFF(decrease) = - 3.9 + 25.6*LOG(PUMP AGE) and

EFF(decrease) = - 1.4 + 22.14*LOG(PUMP AGE).

The first equation was developed using the real pump efficiency determined from the characteristic curves given by the manufacturers. The second equation was developed assuming the pump efficiency decrease equal to 75% minus the actual pump efficiency.

Both equations were statistically significant (α=0.05) with R-squares of 0.37 and 0.34, respectively.

These equations may be incorporated into the model and computer program ICEASE (Irrigation Cost Estimator and System Evaluator) for economical considerations on the impact of pump efficiency decline through the years.